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BLACK SHALE STUDIES
IN KENTUCKY

QUARTERLY REPORT

MARCH, 1979

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1.0 Executive Summary

The quarter has been devoted to the compilation of geochemical data obtained for the eastern Kentucky outcrop belt. The completion and submission of this data realizes a Task Milestone for the project. The compilation is given with this report.

The rest of the quarter was spent in putting together formatted data for submission to the EGSP data bank. This is now complete and submission will take place following packaging.

Considerable steps were taken with regard to statistical evaluation of the black-shale geochemical data. All data on hand are now on disk and readily accessible to the statistics libraries available to us. No further programming is envisaged. There is, however, substantial geochemical data generated by various EGSP contractors which we do not have at this time.

CHEMICAL AND NORMATIVE MINERALOGICAL DATA FOR
THE OHIO AND CHATTANOOGA SHALES IN KENTUCKY

KENTUCKY RESEARCH GROUP
DEPARTMENT OF GEOLOGY
UNIVERSITY OF KENTUCKY

CONTRACT NO. DE-AC21-76MC05202

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I. GEOLOGIC SETTING AND SAMPLING

The Upper Devonian-Lower Mississippian, black-shale sequence has been studied in detail along the arc-shaped outcrop belt on the eastern flank of the Cincinnati Arch in Kentucky. Detailed stratigraphic investigations by Swager (1978) employed twelve sections which ranged from 61 meters to 9.2 meters in thickness. The measured sections were completely described, photographed and sampled at a fixed interval. Gamma-ray logs were prepared for each section by outcrop scintillometry. The results of this study were presented in the University of Kentucky Research Group Annual Report for Contract EY-76-C-05-5202, Fiscal 1977. The locations of the measured sections are presented in Fig. 1 and a schematic cross section along the east-central outcrop belt showing the internal lithostratigraphic units is given as Fig. 2.

The depositional environment of the black-shale sequence has received much attention and speculation. Some workers have proposed a deep-water origin (e.g. Rich, 1951; Lewis and Schwietering, 1971) while others favor a shallow-water environment (Stockdale, 1939; Conant, 1956; Swanson, 1956; Conant and Swanson, 1961). Recent work by Lineback (1968), Griffith (1977) and Provo (1977) suggest, however, that water depth may be a lesser factor in black-shale deposition. They favor controls due to a thermally stratified water column. It is hoped that the geochemical data presented here will eventually contribute to a more consistent model for the depositional environment of this unit. The data are also important to our studies on the overall economic evaluation of the black-shale in Kentucky and the possible relationships between inorganic chemistry, kerogen type, kerogen maturation and gas production. These data also add significantly to the sample population being used for statistical analysis of black-shale geochemical data.

Figure 2. Schematic cross-section along the eastern Kentucky outcrop belt showing the internal stratigraphic units.

II. ANALYTIC TECHNIQUES

a. Chemical Determinations - Major Elements

Those elements normally making up the major proportion of rock material - Si, Ti, Al, Fe, Mn, Mg, Ca, Na, K, P, S - were determined by X-ray fluorescence spectrometry. Samples were ashed at 550°C previous to analysis. This temperature removes all the organic material but is below the level of thermal dissociation of the carbonates. Previous to ashing the samples were crushed in a jaw-crusher and reduced to -200 mesh in a disc-grinder equipped with ceramic plates. Sample powders were pressed into boric-acid backed pellets at 15 tons pressure.

All X-ray fluorescence determinations were made on a Philips 1410/70 X-ray spectrometer. Instrumental settings for the major elements are given in Table 1. Corrections for Ca interference on P were made according to Fabbi (1971). Results are presented in Table A1 of Appendix A. This data is also presented in log form in Figs. 3-11 in Appendix B.

Trace Elements

Concentrations for the elements B, Ba, Cd, Co, Cr, Cu, Ga, Mo, Nb, Ni, Pb, Rb, Sr, Th, U, V, Y, Zn, and Zr are presented in Table A2 of Appendix A. Chemical logs for these elements are given as Figs. 12-30 in Appendix B.

Boron was determined by optical emission spectrography and uranium and thorium by gamma-ray spectrometry. All other determinations were made by X-ray spectrometry on the same neat pellets used for major element determinations. The X-ray procedures for determining mass absorption coefficients and backgrounds were essentially those of Feather and Willis (1976). Instrumental settings for the Philips 1410/70 spectrometer are given in Table 2.

Gamma-ray spectrometric determinations of U and Th employed a 3" x 3" NaI (Th) detector coupled with a Tracor/Northern 1705 analyzer with 1024 channels. Samples were approximately 150g packed in tinned aluminum cans which were sealed and allowed to reequilibrate for at least two weeks prior to counting. The samples were assumed to be in secular isotopic equilibrium and the Tl^{208} photo-peak (2.615 MeV) was used to determine Th. The Bi^{214} Photo-peak (1.76 MeV) was used to determine U. Background and interference stripping corrections were made according to the procedures of Adams and Gasparini (1970).

TABLE 1
Instrumental Settings for the X-ray Fluorescent
Determination of Major Elements

<u>Element</u>	<u>Peak</u>	<u>Source (KVA/ma)</u>	<u>Crystal</u>	<u>PHS (E/ΔE)</u>	<u>Counter</u>	<u>Path</u>
Si	K $\alpha_{1,2}$	Cr (45/35)	PET	2.5/5.0	FP	Vacuum
Ti	K $\alpha_{1,2}$	Cr (45/40)	LiF (200)	2.5/5.0	FP	Air
Al	K $\alpha_{1,2}$	Cr (45/40)	ADP	2.5/5.0	FP	Vacuum
Fe	K $\alpha_{1,2}$	Cr (45/35)	LiF (200)	3.0/7.5	Sc	Air
Mn	K $\alpha_{1,2}$	W (50/40)	LiF (200)	2.0/4.4	FP	Air
Mg	K $\alpha_{1,2}$	Cr (50/40)	TAP	2.7/5.4	FP	Vacuum
Ca	K $\alpha_{1,2}$	Cr (45/40)	LiF (200)	2.5/5.0	FP	Air
Na	K $\alpha_{1,2}$	Cr (50/40)	TAP	2.5/6.0	FP	Vacuum
K	K $\alpha_{1,2}$	Cr (30/20)	PET	2.5/5.0	FP	Vacuum
F	K $\alpha_{1,2}$	Cr (45/40)	PET	2.8/2.0	FP	Vacuum
S	K $\alpha_{1,2}$	Cr (45/40)	PET	2.5/5.0	FP	Vacuum

TABLE 2
Instrumental Settings for X-ray Fluorescent
Determinations of Trace Elements

<u>Element</u>	<u>Peak</u>	<u>Source (KUA/ma)</u>	<u>Crystal</u>	<u>PHS (E/ΔE)</u>	<u>Counter</u>	<u>Path</u>
Ba	$L\alpha_1$	W(50/40)	LiF(200)	2.0/4.4	FP	Air
Cd	$K\alpha_{1,2}$	W(50/40)	PET	2.5/5.3	FP	Vacuum
Co	$K\alpha_{1,2}$	W(50/40)	LiF(200)	2.0/4.5	Sc	Air
Cr	$K\alpha_{1,2}$	W(50/40)	LiF(200)	2.0/4.5	Sc	Air
Cu	$K\alpha_{1,2}$	W(50/40)	LiF(200)	2.0/4.5	Sc	Air
Ga	$K\alpha_{1,2}$	W(50/40)	LiF(220)	2.0/4.5	Sc	Air
Mo	$K\alpha_{1,2}$	W(50/40)	LiF(220)	2.0/4.5	Sc	Air
Nb	$K\alpha_{1,2}$	W(50/40)	LiF(220)	2.0/4.5	Sc	Air
Ni	$K\alpha_{1,2}$	W(50/40)	LiF(200)	2.0/4.5	Sc	Air
Pb	$L\alpha_1$	W(50/40)	LiF(220)	2.0/4.5	Sc	Air
Rb	$K\alpha_{1,2}$	Mo(50/40)	LiF(220)	2.0/4.7	Sc	Air
Sr	$K\alpha_{1,2}$	Mo(50/40)	LiF(220)	2.0/4.7	Sc	Air
V	$K\alpha_{1,2}$	W(50/40)	LiF(200)	2.0/4.4	FP	Air
Y	$K\alpha_{1,2}$	Mo(50/40)	LiF(220)	2.0/4.7	Sc	Air
Zn	$K\alpha_{1,2}$	W(50/40)	LiF(220)	2.0/4.5	Sc	Air
Zr	$K\alpha_{1,2}$	Mo(50/40)	LiF(220)	2.0/4.7	Sc	Air

b. Normative Mineralogy

The very fine grained nature of the shale and its high organic content preclude the use of the polarizing microscope for quantitative mineral determination. This same high content of organic materials in the black shales means that time consuming methods of sample preparation are needed to ascertain the mineralogic composition by X-ray diffraction. Resultant norms are given in Table A3 of Appendix A and presented in log form as Figs. 31-38 in Appendix B.

Quantitative mineral analysis based on chemical analysis (major element oxides) is a fast and relatively accurate approach to determine the mineralogy of a large number of samples. However, in order to use the chemical data to the best advantage, the number of minerals and their distribution in the shales must be approximately known so that the proper proportion of the oxides can be assigned to the various minerals.

The normative mineral assemblage was based on detailed mineral analysis of the Chattanooga shale in Tennessee (Conant and Swanson, 1961 and Bates, 1957) and a combination of petrographic and X-ray diffraction work in southeastern Kentucky (Miller, 1978).

The following is a list of mineral suite reported for the Chattanooga shale with approximately weight percentages in parenthesis; quartz (20-25), feldspar (10, orthoclase most abundant, and plagioclase), clay and mica (25-30, illite dominant clay, with kaolinite, and montmorillonite, muscovite primary mica, with biotite, chlorite, and glauconite), pyrite (10-15), organic (15-20), accessories (5, apatite, rutile, tourmaline, and zircon), and carbonates (highly variable, calcite, dolomite, and siderite) (Conant and Swanson, 1961, Bates, 1957, and Miller, 1978).

ILLITE

Normative illite (muscovite-illite) was calculated using the formula,

which is equivalent in weight percent to 7 percent K_2O , 2 percent MgO , 1 percent FeO , 4 percent Fe_2O_3 , 1 percent TiO_2 , 27 percent Al_2O_3 , 53 percent SiO_2 , and 5 percent H_2O . This formula is based on the average for many illites and hydromuscovites reported in the literature (Armands, 1972) and on the assumption that the illite is not pure, containing the contaminants iron, titanium, and magnesium.

K-FELDSPAR

Normative feldspar was calculated using the formula,

which breaks down to (in weight percent) 65 percent SiO_2 , 18 percent Al_2O_3 and 17 percent K_2O (Armands, 1972).

All of the available potassium was proportion between the minerals illite and K-feldspar in the ratio 75/25 respectively. This ratio was chosen because 25 percent of the average potassium concentration would be needed to form 6 percent K-feldspar, the average feldspar value in these black shales (Bates, 1957).

In the calculation of normative illite and K-feldspar an excess or deficiency of aluminum will appear. If there was an excess of aluminum then the remaining aluminum was used to form normative kaolinite. If there was insufficient aluminum to form both minerals, then all the potassium was recalculated to form normative illite and the remaining potassium was used to form normative kaolinite. The necessary amount of FeO , Fe_2O_3 , TiO , and MgO were then assigned to the illite.

PYRITE

Normative pyrite was calculated using the formula, FeS_2 . Pyrite was calculated using total sulfur and total iron. In the case where one-half the total sulfur (Fe to S ratio is 1 to 2) was greater than the total iron value, the difference between the sulfur in pyrite and the total sulfur was calculated as excess sulfur. In the case where one-half the total sulfur was less than the total iron value, excess iron was calculated by subtracting the total iron from the iron in pyrite.

If an excess of iron existed it was recalculated to FeO , the iron in illite was similarly recalculated. The difference between the recalculated excess iron and the recalculated iron in illite was then determined. If the difference between FeO excess and FeO in illite was greater than zero, normative chlorite was formed.

CHLORITE

Normative chlorite was calculated using the formula,

this corresponds to (in weight percent) 29 percent SiO_2 , 17 percent Al_2O_3 , 21 percent FeO , 21 percent MgO , and 12 percent H_2O .

QUARTZ

Normative quartz (SiO_2) was derived from the difference between total silica and the silica contained in the silicate minerals.

CARBONATE

Normative carbonate represents the sum of CaCO_3 , calculated from the difference between total calcium and the calcium used in apatite and MgCO_3 , calculated from the difference between total magnesium and the magnesium used in the other minerals.

ACCESSORIES

Accessory minerals used in the norm calculation include apatite and rutile.

"ORGANIC CARBON"

The sum of the normative minerals, illite+quartz+chlorite+kaolinite+carbonate+accessories+any manganese and sodium was subtracted from one hundred. The remainder, 'R', determined in this way probably represents a good first approximation of the amount of organic material in the black shale.

The average value for 'R' in 132 black shale samples is 14.02 percent, in close agreement with the 10.4+ 1.5 percent organic carbon determined by Vine and Tourtelot (1970) for the Chattanooga Shale in central Tennessee and northern Alabama and the 15-20 percent cited by Conant and Swanson (1961).

REFINEMENT OF THE NORM

Detailed mineralogic studies on a selected group of black shale samples from the eastern Kentucky outcrop belt are currently in progress (Woock, personal comm., 1979). When this work is completed and a better understanding of the mineral types and compositions are known, modifications in the calculation of the norm can be introduced.

III. CONTRIBUTORS

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APPENDIX A

Data Listings for the Black-shale in the
Eastern Kentucky Outcrop Belt.

Table 3

CHATTANOOGA SHALE OUTCROP DATA

NO.	SECT	METER/FT	T	P	SI	TI	AL	FE	MG	CA	NA
1	LE	0.0(0)	G	6	12.32	0.08	10.37	17.29	.	0.10	.
2	LE	0.3(1)	G	6	29.84	0.63	9.42	3.80	.	0.10	.
3	LE	2.9(9.7)	B	6	26.63	0.53	9.34	5.94	0.52	0.07	0.19
4	LE	3.8(12.5)	B	6	24.80	0.50	8.14	4.25	0.50	0.06	0.19
5	LE	4.1(13.5)	G	6	29.44	0.57	10.39	4.00	0.74	0.07	0.20
6	LE	5.3(17.5)	B	6	28.81	0.51	7.88	2.88	0.47	0.06	0.25
7	LE	6.1(20)	B	6	28.46	0.55	8.96	1.67	0.58	0.07	0.26
8	LE	7.6(25)	B	5	28.48	0.55	8.71	3.59	0.57	0.06	0.26
9	LE	9.1(30)	B	5	26.45	0.52	7.56	4.02	0.48	0.06	0.22
10	LE	10.7(35)	B	5	30.68	0.62	9.55	2.51	.	0.08	.
11	LE	12.2(40)	B	5	29.30	0.45	6.48	4.96	0.28	0.07	0.29
12	LE	13.7(45)	B	5	29.94	0.43	6.70	3.96	0.38	0.28	0.29
13	LE	15.2(50)	B	5	29.63	0.40	6.93	4.30	0.43	0.07	0.23
14	LE	16.8(55)	B	5	28.44	0.49	8.11	4.38	0.54	0.07	0.25
15	LE	18.3(60)	B	5	27.50	0.47	7.88	4.58	0.49	0.06	0.24
16	LE	19.8(65)	B	5	28.67	0.49	7.63	4.71	0.45	0.06	0.26
17	LE	21.3(70)	B	5	28.36	0.51	7.90	3.98	0.44	0.06	0.22
18	LE	22.9(75)	B	5	31.27	0.45	7.62	4.29	0.72	0.18	0.31
19	LE	24.4(80)	B	5	30.83	0.45	7.28	4.24	0.63	0.13	0.26
20	LE	25.9(85)	B	5	29.77	0.49	8.12	4.69	0.67	0.11	0.28
21	LE	27.4(90)	B	4	27.52	0.44	7.33	4.94	0.66	0.55	0.31
22	LE	29.0(95)	B	4	28.50	0.44	7.46	5.02	0.54	0.46	0.31
23	LE	30.5(100)	B	4	29.08	0.48	8.41	5.32	0.64	0.08	0.29
24	LE	32.0(105)	B	4	28.19	0.53	8.93	4.82	0.91	0.19	0.27
25	LE	33.5(110)	B	4	28.73	0.54	8.61	5.15	0.80	0.08	0.31
26	FL	0.0(0)	B	5	25.93	0.45	6.60	6.27	0.51	0.07	0.27
27	FL	4.6(15)	B	5	28.14	0.49	7.95	3.82	0.62	0.07	0.29
28	FL	6.1(20)	B	5	31.03	0.49	8.50	2.65	0.67	0.07	0.24
29	FL	16.8(55)	B	5	26.96	0.44	7.46	4.62	0.76	0.07	0.24
30	FL	22.9(75)	B	4	27.27	0.58	9.83	4.22	0.67	0.07	0.30
31	FL	24.4(80)	B	3	28.17	0.62	9.76	1.95	0.74	0.07	0.33
32	FL	27.4(90)	B	3	26.72	0.58	9.34	4.26	0.70	0.07	0.29
33	FL	28.0(91.7)	G	2	29.04	0.60	10.30	4.42	0.91	0.06	0.26
34	FL	29.0(95)	B	2	26.32	0.61	10.10	2.51	0.73	0.07	0.22
35	FL	30.5(100)	B	2	28.49	0.62	9.10	2.42	0.33	0.08	0.29
36	FL	31.2(102.4)	G	2	27.55	0.53	9.30	5.80	1.01	0.13	0.26
37	FL	32.0(105)	B	1	28.93	0.60	9.92	2.77	0.85	0.07	0.21
38	FL	33.5(110)	B	1	26.74	0.56	8.14	2.87	0.71	0.06	0.24
39	FL	35.1(115)	B	1	26.57	0.62	10.50	2.24	0.57	0.07	0.20
40	FL	36.6(120)	B	1	29.56	0.57	8.34	1.64	0.70	0.07	0.28
41	FL	38.1(125)	B	1	28.65	0.52	7.91	3.01	0.69	0.07	0.23
42	FL	39.6(130)	B	1	27.61	0.49	8.36	2.52	0.77	0.06	0.24
43	FL	41.1(135)	B	1	27.26	0.51	7.73	4.00	0.72	0.13	0.25
44	FL	42.7(140)	B	1	23.15	0.46	8.03	3.81	0.75	0.05	0.20
45	FL	44.2(145)	B	1	24.86	0.55	8.92	2.08	0.67	0.06	0.21
46	FL	45.0(147.5)	G	1	27.99	0.66	11.19	3.42	0.78	0.07	0.21
47	FL	54.9(180)	B	.	29.49	0.36	7.00	2.99	0.48	0.07	0.20
48	RW	.7(2.3)	B	5	19.76	0.35	6.00	13.92	.	2.12	.
49	RW	0.8(2.5)A	B	5	26.23	0.61	9.64	5.12	.	0.23	.

Table 3 (cont.)

CHATTANOOGA SHALE OUTCROP DATA

NO.	K	S	MN	P
1	0.45	7.17	0.07	0.07
2	3.23	0.82	0.01	0.03
3	3.28	8.26	0.00	0.03
4	3.17	7.49	0.00	0.04
5	4.02	5.46	0.00	0.03
6	3.42	4.53	0.00	0.02
7	3.55	1.08	0.00	0.02
8	3.47	1.83	0.00	0.02
9	3.21	2.17	0.00	0.02
10	3.96	1.50	0.01	0.03
11	2.56	0.85	0.00	0.03
12	2.61	1.95	0.00	0.03
13	2.76	0.52	0.00	0.02
14	3.33	2.41	0.00	0.02
15	3.27	2.30	0.00	0.02
16	3.08	2.86	0.00	0.02
17	3.31	5.28	0.00	0.03
18	2.76	4.57	0.01	0.02
19	2.69	5.23	0.01	0.02
20	3.13	6.21	0.00	0.02
21	2.88	8.31	0.00	0.02
22	3.04	8.69	0.00	0.02
23	3.41	4.44	0.00	0.02
24	3.37	1.07	0.02	0.02
25	3.27	1.93	0.01	0.02
26	2.48	1.94	0.00	0.03
27	3.12	1.34	0.00	0.03
28	3.17	0.57	0.00	0.02
29	2.86	3.04	0.00	0.03
30	3.66	3.35	0.00	0.02
31	3.50	0.44	0.00	0.02
32	3.33	1.83	0.00	0.02
33	4.06	0.73	0.00	0.15
34	3.38	0.58	0.00	0.02
35	3.45	1.02	0.00	0.03
36	3.60	2.50	0.00	0.02
37	3.65	0.01	0.00	0.02
38	3.14	1.00	0.00	0.02
39	3.08	0.03	0.00	0.05
40	3.02	0.60	0.00	0.02
41	2.97	0.62	0.00	0.02
42	3.23	1.04	0.00	0.03
43	2.84	1.44	0.00	0.03
44	3.23	0.65	0.00	0.02
45	3.21	0.14	0.00	0.02
46	3.60	0.17	0.00	0.02
47	2.51	1.83	0.00	0.02
48	2.18	16.77	0.02	0.77
49	3.73	5.31	0.03	0.03

Table 3 (cont.)

CHATTANOOGA SHALE OUTCROP DATA

NO.	SECT	METER/FT	T	P	SI	TI	AL	FE	MG	CA	NA
50	RW	0.8(2.5)B	B	5	25.90	0.61	9.20	3.58	.	0.06	.
51	RW	1.5(5)	B	5	26.93	0.52	7.56	5.94	0.73	0.06	0.24
52	RW	2.5(8.2)	B	5	25.05	0.58	8.19	1.73	.	0.07	.
53	RW	3.0(10)	B	5	25.52	0.50	8.24	4.35	0.65	0.06	0.23
54	RW	4.8(15.7)A	B	5	21.86	0.43	6.12	10.81	0.32	0.13	0.24
55	RW	4.8(15.7)B	B	5	25.53	0.52	3.63	3.63	0.71	0.07	0.27
56	RW	7.6(25)	B	5	26.54	0.58	8.53	4.03	0.61	0.06	0.30
57	RW	12.0(39.6)	B	5	26.15	0.54	8.72	5.51	0.70	0.06	0.30
58	RW	29.9(98.1)	B	3	28.48	0.47	7.38	3.22	.	0.08	.
59	RW	30.4(99.6)A	B	3	26.21	0.53	8.65	4.84	0.90	0.07	0.26
60	RW	30.4(99.6)B	B	3	28.62	0.49	7.93	3.63	0.67	0.07	0.26
61	RW	40.3(132.3)	B	1	27.50	0.48	7.64	4.48	0.69	0.07	0.25
62	RW	40.3(132.3)	B	1	26.41	0.57	9.40	3.41	0.73	0.07	0.29
63	RW	42.1(138)	B	1	25.32	0.53	7.33	5.32	.	0.07	.
64	RW	44.2(145)	B	1	22.84	0.44	7.28	12.03	0.73	1.46	0.24
65	RW	45.0(147.5)	B	1	29.74	0.58	8.93	2.92	.	0.10	.
66	RW	59.4(195)	B	.	30.23	0.51	7.83	3.25	0.61	0.07	0.26
67	RW	66.4(213)	B	.	27.62	0.58	9.43	2.52	0.73	0.06	0.29
68	PO	0.0(0)	G	.	20.36	0.25	5.35	2.22	6.74	12.00	0.18
69	PO	1.5(5)	B	.	21.91	0.30	5.85	2.04	6.02	9.97	0.25
70	PO	3.0(10)	B	.	19.71	0.28	5.73	2.98	3.18	6.19	0.25
71	PO	4.6(15)	B	.	22.03	0.33	5.98	2.37	3.36	5.20	0.27
72	PO	6.1(20)	B	.	18.58	0.27	5.31	3.22	2.11	3.81	0.23
73	PO	7.6(25)A	B	.	24.15	0.52	7.99	3.44	0.57	0.06	0.31
74	PO	7.6(25)B	B	.	21.43	0.46	7.17	5.93	0.30	0.05	0.26
75	PO	9.1(30)	B	5	25.43	0.56	7.67	5.39	0.39	0.06	0.27
76	PO	10.3(35.5)	B	5	26.79	0.59	7.82	1.82	0.40	0.05	0.34
77	PO	12.2(40)	B	5	25.06	0.54	7.15	2.42	0.42	0.06	0.32
78	PO	13.7(45)	B	5	25.55	0.51	7.74	4.43	0.52	0.37	0.31
79	PO	15.2(50)	B	5	24.96	0.48	7.78	5.60	0.56	0.07	0.26
80	PO	16.8(55)	B	5	30.15	0.51	7.91	1.65	0.63	0.07	0.27
81	PO	18.3(60)	B	5	30.46	0.47	7.92	1.46	0.64	0.07	0.23
82	PO	19.8(65)	B	5	27.30	0.51	7.74	3.34	0.63	0.07	0.26
83	PO	21.3(70)	B	4	28.93	0.48	7.20	3.09	0.57	0.07	0.26
84	PO	22.5(75)	B	4	28.42	0.46	7.29	2.94	0.64	0.07	0.27
85	PO	24.4(80)	B	4	27.67	0.51	8.02	3.08	0.69	0.07	0.28
86	PO	25.9(85)	B	4	27.18	0.53	8.35	3.47	0.73	0.07	0.26
87	PO	29.0(95)	G	4	21.00	0.29	6.88	4.12	0.50	9.28	0.19
88	PO	30.5(100)	B	4	25.52	0.52	8.38	3.83	0.73	0.21	0.27
89	PO	31.2(102.5)	B	3	25.75	0.54	8.37	3.71	0.66	0.14	0.27
90	PO	32.8(107.5)	B	3	25.93	0.55	8.80	2.98	0.73	0.10	0.28
91	PO	32.9(108)	G	2	29.72	0.55	10.43	2.89	0.92	0.06	0.30
92	PO	33.7(110.5)	G	2	28.43	0.54	10.28	3.18	0.88	0.06	0.29
93	PO	34.4(113)	G	2	30.43	0.58	10.27	2.69	0.93	0.07	0.28
94	PO	37.5(123)	B	1	26.92	0.53	8.23	3.60	0.79	0.08	0.27
95	PO	39.0(128)	B	1	27.56	0.50	7.69	3.11	0.70	0.08	0.29
96	PO	40.5(133)	B	1	27.74	0.48	7.62	2.83	0.63	0.13	0.28
97	PO	42.1(138)	B	1	26.78	0.43	7.21	2.64	0.68	0.19	0.24
98	PO	43.6(143)	B	1	26.35	0.43	6.77	2.21	0.58	0.22	0.26

Table 3 (cont.)

CHATTANOOGA SHALE OUTCROP DATA

NO.	K	S	MN	P
50	3.96	3.15	0.02	0.04
51	2.82	1.51	0.01	0.03
52	3.36	1.59	0.00	0.03
53	3.37	2.42	0.00	0.02
54	2.52	5.49	0.00	0.05
55	3.51	2.62	0.00	0.02
56	3.40	2.01	0.00	0.02
57	3.54	2.78	0.00	0.02
58	2.97	1.75	0.00	0.02
59	3.41	1.43	0.00	0.03
60	3.24	2.13	0.00	0.02
61	3.23	2.66	0.00	0.02
62	3.44	1.23	0.00	0.02
63	3.40	3.06	0.01	0.02
64	2.76	7.08	0.02	0.03
65	3.40	0.57	0.00	0.02
66	3.04	1.35	0.00	0.02
67	3.67	1.26	0.00	0.02
68	2.31	2.41	0.44	0.09
69	2.66	4.45	0.06	0.03
70	2.56	8.20	0.14	0.09
71	2.80	5.94	0.05	0.08
72	2.50	8.12	0.08	0.10
73	3.04	2.13	0.00	0.03
74	2.67	2.45	0.01	0.04
75	2.85	2.13	0.00	0.02
76	2.93	0.66	0.00	0.02
77	2.79	2.05	0.00	0.02
78	3.25	3.99	0.00	0.03
79	3.16	2.32	0.00	0.03
80	3.16	0.80	0.00	0.02
81	3.16	0.24	0.00	0.02
82	3.20	1.51	0.00	0.02
83	2.82	1.01	0.00	0.02
84	2.89	1.14	0.00	0.02
85	3.26	1.06	0.00	0.02
86	3.53	1.59	0.00	0.03
87	2.86	21.08	0.07	0.03
88	3.53	2.92	0.00	0.02
89	3.47	1.55	0.00	0.02
90	3.61	1.11	0.00	0.02
91	4.19	1.98	0.00	0.02
92	4.13	2.09	0.00	0.02
93	4.30	0.51	0.00	0.02
94	3.34	0.90	0.00	0.03
95	3.22	1.54	0.00	0.04
96	3.09	1.55	0.00	0.04
97	2.84	0.90	0.00	0.16
98	2.83	1.91	0.00	0.03

Table 3 (cont.)

CHATTANOOGA SHALE OUTCROP DATA

NO.	SECT	METER/FT	T	P	SI	TI	AL	FE	MG	CA	NA
99	PU	45.1(148)	B	1	25.59	0.40	6.71	2.32	0.64	0.09	0.22
100	PU	46.6(153)	B	1	23.66	0.48	7.53	3.43	0.73	0.07	0.27
101	PO	47.9(157)	B	.	24.45	0.42	7.31	3.75	0.53	0.06	0.25
102	ES	0.3(1.1)	G	.	21.65	0.46	8.25	3.36	4.09	7.16	0.21
103	ES	3.0(10)	D	.	12.36	0.00	1.16	1.55	0.67	23.21	0.11
104	ES	4.6(15)	G	.	19.86	0.25	5.83	1.56	.	10.90	.
105	ES	6.1(20)	B	.	16.09	0.19	4.76	1.72	5.31	9.97	0.19
106	ES	7.3(24)	G	5	17.85	0.15	4.31	1.84	7.77	15.19	0.17
107	ES	8.3(27.3)	B	5	21.87	0.35	6.30	2.49	2.78	4.38	0.19
108	ES	8.5(28)	G	5	26.80	0.47	8.14	2.84	2.60	3.05	0.24
109	ES	8.6(28.2)	G	5	23.16	0.31	5.72	2.55	5.56	9.90	0.25
110	ES	10.1(33)	B	5	26.19	0.35	7.93	2.77	1.24	0.61	0.33
111	ES	15.2(50)	B	5	24.53	0.54	7.73	4.24	0.45	0.06	0.22
112	ES	18.3(60)A	B	5	27.46	0.56	8.88	3.15	0.76	0.06	0.28
113	ES	18.3(60)B	B	5	26.10	0.52	8.41	5.63	0.66	0.06	0.23
114	MA	1.5(5)	B	5	21.03	0.31	6.09	3.22	2.45	3.61	0.25
115	MA	3.0(10)	B	5	23.28	0.36	6.88	2.79	1.61	1.53	0.28
116	MA	6.1(20)	B	5	28.41	0.47	7.36	3.42	0.71	0.08	0.26
117	MA	7.6(25)	B	4	30.44	0.53	7.92	2.52	0.72	0.06	0.19
118	MA	12.2(40)	B	4	25.83	0.52	8.31	4.46	0.82	0.07	0.26
119	MA	13.0(42.5)	G	2	29.19	0.55	9.96	3.23	1.24	0.07	0.33
120	MA	13.1(42.8)	B	2	26.25	0.52	8.66	3.86	0.89	0.08	0.25
121	MA	13.3(43.6)	G	2	28.55	0.53	9.81	3.77	1.14	0.07	0.32
122	MA	13.4(44.1)	B	2	24.92	0.50	8.02	3.45	0.80	0.07	0.26
123	MA	13.7(45)	B	2	25.94	0.53	8.44	3.31	0.87	0.07	0.28
124	MA	13.8(45.1)	G	2	28.43	0.53	9.60	4.03	1.18	0.07	0.32
125	MA	15.2(50)	B	1	26.74	0.55	8.51	3.47	0.82	0.07	0.25
126	MA	16.8(55)	B	1	27.52	0.51	8.15	3.20	0.78	0.06	0.26
127	CA	0.5(1.5)	G	4	29.65	0.54	9.40	3.77	1.02	0.14	0.38
128	CA	1.5(5)	B	3	26.64	0.51	7.49	3.24	0.70	0.06	0.31
129	CA	3.0(10)	B	3	27.73	0.51	7.31	3.73	0.71	0.08	0.28
130	CA	4.6(15)	B	2	25.75	0.49	7.96	3.24	0.82	0.07	0.27
131	CA	6.1(20)	B	1	25.22	0.48	7.44	3.24	0.78	0.31	0.30
132	CA	7.6(25)	B	1	24.60	0.48	7.54	3.12	0.91	0.08	0.25
133	CA	9.1(30)	B	1	24.24	0.46	6.69	3.17	0.75	0.16	0.25
134	CA	10.7(35)	B	1	22.87	0.46	7.02	3.09	0.86	0.16	0.24
135	CA	11.7(38.5)	B	1	24.10	0.49	7.70	2.79	0.84	0.15	0.30
136	PU	DUF(DUF)	.	.	21.35	0.06	2.46	1.74	7.20	14.62	0.17
137	PU	0.0(0)	B	5	24.76	0.51	7.77	3.15	1.14	0.49	0.30
138	PU	1.5(5)	B	5	23.65	0.50	6.79	4.39	0.46	0.07	0.22
139	PU	3.0(10)	B	5	24.80	0.55	6.93	6.11	0.27	0.10	0.25
140	PU	4.6(15)	B	4	26.00	0.53	7.49	4.11	0.45	0.07	0.24
141	PU	6.1(20)	B	4	25.42	0.54	8.10	6.74	0.77	0.09	0.28
142	PU	7.6(25)	B	4	26.32	0.55	8.82	3.59	0.76	0.07	0.28
143	PU	9.1(30)	B	3	24.36	0.51	7.64	3.11	0.80	0.07	0.26
144	PU	10.7(35)	B	2	24.58	0.48	7.40	2.91	0.83	0.08	0.26
145	PU	12.2(40)	B	1	24.52	0.47	6.99	3.66	0.82	0.12	0.25
146	PU	13.7(45)	B	1	24.71	0.46	7.25	2.81	0.82	0.25	0.27
147	PU	15.0(49.1)	B	1	21.33	0.39	6.19	4.95	0.58	0.39	0.20

Table 3 (cont.)

CHATTANOOGA SHALE OUTCROP DATA

NO.	K	S	MN	P
99	2.74	0.72	0.00	0.03
100	3.15	1.25	0.00	0.05
101	2.87	1.36	0.00	0.01
102	3.74	6.55	0.04	0.14
103	0.00	1.16	0.09	0.02
104	2.65	6.51	0.05	0.06
105	0.00	9.54	0.04	0.10
106	1.77	7.27	0.07	0.02
107	2.94	4.81	0.02	0.08
108	3.80	4.85	0.02	0.02
109	2.59	3.51	0.09	0.01
110	3.47	3.93	0.01	0.06
111	2.93	1.82	0.00	0.03
112	3.57	1.34	0.00	0.02
113	3.42	3.99	0.00	0.03
114	3.04	5.51	0.03	0.09
115	3.32	3.39	0.03	0.07
116	3.27	2.44	0.00	0.04
117	3.16	2.36	0.00	0.02
118	3.60	6.86	0.00	0.03
119	4.34	2.17	0.00	0.02
120	3.83	4.57	0.00	0.04
121	4.39	2.35	0.00	0.02
122	3.42	1.28	0.00	0.04
123	3.63	1.30	0.00	0.03
124	4.36	2.20	0.00	0.02
125	3.66	3.80	0.00	0.03
126	3.41	3.61	0.00	0.03
127	4.29	2.03	0.00	0.03
128	3.52	1.51	0.00	0.01
129	2.35	3.37	0.00	0.01
130	3.80	4.81	0.00	0.02
131	3.53	2.84	0.00	0.02
132	3.56	1.37	0.00	0.04
133	3.12	4.39	0.00	0.05
134	3.32	1.12	0.00	0.08
135	3.48	0.75	0.00	0.12
136	0.72	4.98	0.15	0.51
137	3.32	1.98	0.01	0.07
138	3.00	2.48	0.00	0.03
139	3.33	4.66	0.00	0.04
140	3.35	1.98	0.00	0.03
141	3.62	3.15	0.00	0.03
142	3.80	2.19	0.00	0.03
143	3.29	1.34	0.00	0.05
144	3.17	1.26	0.00	0.06
145	3.05	1.78	0.00	0.12
146	3.14	1.94	0.00	0.19
147	2.77	2.89	0.00	0.31

Table 3 (cont.)

CHATTANOOGA SHALE OUTCROP DATA

NO.	SECT	METER/FT	T	P	SI	TI	AL	FE	MG	CA	NA
148	RU	0.0(0)	B	4	25.00	0.55	8.63	2.98	0.81	0.15	0.50
149	RU	1.5(5)	G	4	26.16	0.56	7.95	7.76	0.54	0.06	0.32
150	RU	3.0(10)	B	4	24.23	0.50	7.07	5.54	0.43	0.07	0.33
151	RU	4.6(15)	B	3	22.41	0.48	7.06	6.04	0.56	0.24	0.29
152	RU	6.1(20)	B	2	24.70	0.53	6.59	6.57	0.31	0.07	0.26
153	RU	6.4(24)	G	2	25.49	0.61	9.58	8.79	.	0.07	.
154	RU	7.6(25)	B	1	24.84	0.54	7.92	5.00	0.60	0.06	0.41
155	RU	9.1(30)	B	1	24.71	0.51	7.81	5.09	0.67	0.07	0.36
156	RU	10.7(35)	B	1	26.16	0.51	7.73	2.69	0.76	0.07	0.28
157	CU	0.0(0)	B	3	26.21	0.57	10.25	4.47	1.16	0.08	0.36
158	CU	1.5(5)	B	3	23.22	0.09	7.19	8.19	0.77	0.17	0.26
159	CU	3.0(10)	B	3	28.64	0.61	6.65	4.37	0.38	0.06	0.21
160	CU	4.6(15)	B	2	26.43	0.56	8.01	3.63	0.68	0.08	0.26
161	CU	6.1(20)	B	1	26.40	0.50	7.46	2.95	0.75	0.09	0.23
162	CU	7.6(25)	B	1	25.82	0.43	7.24	2.91	0.99	0.28	0.27
163	CU	8.7(28.5)	B	1	35.13	0.37	7.14	2.77	1.06	0.21	0.39
164	BU	0.1(0.3)	.	.	23.59	0.39	6.92	1.97	.	3.80	.
165	BU	1.5(5)	.	.	25.06	0.30	6.65	2.36	.	6.44	.
166	BU	2.4(8)	.	.	23.00	0.46	7.15	2.51	.	0.08	.
167	BU	2.7(9)	.	.	27.83	0.52	9.68	2.21	.	0.08	.
168	BU	3.0(10)	.	.	27.02	0.47	8.34	1.84	.	1.10	.
169	BU	3.7(12)	.	.	24.97	0.43	7.56	3.22	.	0.80	.
170	BU	4.3(14)	.	.	25.07	0.37	6.88	2.62	.	2.97	.
171	BU	4.6(15)	.	.	28.12	0.52	9.02	5.53	.	0.07	.
172	BU	4.9(16)	.	.	27.18	0.50	8.62	3.32	.	0.06	.
173	BU	5.5(18)	.	.	28.30	0.55	8.37	2.81	.	0.06	.
174	BU	6.1(20)	.	.	27.43	0.52	8.15	2.64	.	0.06	.
175	BU	6.7(22)	.	.	29.08	0.54	8.24	2.11	.	0.06	.
176	BU	7.3(24)	.	.	28.72	0.54	8.26	2.29	.	0.06	.
177	BU	7.6(25)	.	.	29.27	0.57	9.38	2.27	.	0.07	.
178	BU	7.9(26)	.	.	30.44	0.54	9.18	3.92	.	0.07	.
179	BU	8.5(28)	.	.	25.70	0.47	7.25	3.00	.	0.06	.
180	BU	9.1(30)	.	.	27.04	0.48	7.21	8.14	.	0.06	.
181	BU	10.7(35)	.	.	29.24	0.60	9.01	1.14	.	0.06	.
182	BU	21.2(40)	.	.	29.36	0.60	8.93	2.74	.	0.07	.
183	BU	13.7(45)	.	.	32.61	0.68	8.90	1.63	.	0.07	.
184	BU	15.2(50)	.	.	30.94	0.62	8.46	1.06	.	0.06	.
185	BU	16.8(55)	.	.	18.94	0.42	4.54	8.77	.	0.06	.
186	BU	18.3(60)	.	.	31.32	0.65	8.15	1.82	.	0.06	.
187	BU	19.8(65)	.	.	30.51	0.63	7.77	4.73	.	0.07	.
188	BU	21.3(70)	.	.	27.96	0.41	5.92	3.28	.	0.06	.
189	BU	22.9(75)	.	.	25.71	0.40	5.96	5.37	.	0.07	.
190	BU	24.4(80)	.	.	22.87	0.46	7.00	2.71	.	0.06	.
191	BU	25.0(82)	.	.	22.29	0.46	7.44	2.96	.	0.07	.

Table 3 (cont.)

CHATTANOOGA SHALE OUTCROP DATA

NO.	K	S	MN	P
148	3.62	0.31	0.00	0.08
149	3.55	5.09	0.00	0.03
150	3.45	6.34	0.00	0.05
151	3.41	5.46	0.01	0.03
152	2.98	4.27	0.00	0.02
153	4.18	0.70	0.01	0.08
154	3.67	0.33	0.00	0.03
155	3.60	0.42	0.00	0.03
156	3.44	1.17	0.00	0.07
157	4.54	1.25	0.01	0.03
158	3.33	8.95	0.01	0.05
159	2.86	6.39	0.00	0.03
160	3.71	1.00	0.00	0.03
161	3.39	1.07	0.00	0.06
162	3.25	2.19	0.00	0.10
163	2.63	0.56	0.00	0.02
164	3.33	3.60	0.09	0.02
165	3.07	5.48	0.14	0.08
166	3.47	1.14	0.09	0.02
167	3.73	0.26	0.03	0.02
168	3.98	2.83	0.05	0.03
169	3.59	3.44	0.06	0.03
170	3.33	2.95	0.07	0.03
171	4.14	1.95	0.00	0.06
172	3.86	1.51	0.01	0.03
173	3.78	1.59	0.00	0.02
174	3.69	1.38	0.00	0.03
175	3.55	0.91	0.00	0.02
176	3.66	0.82	0.00	0.02
177	4.16	1.14	0.00	0.02
178	4.07	0.97	0.00	0.03
179	3.33	0.90	0.00	0.02
180	3.46	3.18	0.01	0.03
181	3.80	0.64	0.00	0.05
182	3.86	1.58	0.00	0.03
183	3.63	1.21	0.00	0.02
184	3.47	0.68	0.00	0.02
185	2.57	4.42	0.00	0.02
186	3.30	1.20	0.00	0.02
187	3.58	3.83	0.01	0.02
188	2.62	1.96	0.00	0.02
189	2.76	3.75	0.01	0.04
190	3.40	1.97	0.01	0.04
191	3.60	1.83	0.01	0.05

Table 4

CHATTANOOGA SHALE OUTCROP DATA

	B	BA	CD	CO	CR	CU	GA	MO	NB	NI
1	.	627.5	0.189	290.2	662.4	97.8	34.0	30.5	16.0	27.6
2	.	1510.7	0.041	6.6	7.4	26.5	0.0	41.7	12.4	2.5
3	224	1147.0	0.068	35.2	64.2	74.1	15.7	66.3	10.9	10.0
4	150	12333.8	0.056	17.8	4.7	54.3	14.9	96.6	15.3	11.4
5	220	885.4	0.053	8.3	3.1	26.7	17.5	25.7	10.2	7.9
6	158	21170.2	0.046	4.3	7.1	21.6	5.5	90.6	14.4	6.1
7	163	724.7	0.025	2.6	24.4	6.4	6.9	48.7	8.6	1.4
8	200	705.8	0.046	8.2	2.8	37.0	12.5	95.6	8.7	7.7
9	174	911.7	0.047	7.9	13.6	72.7	7.1	86.8	12.0	4.3
10	.	662.1	0.033	4.1	2.7	0.8	4.3	26.3	6.9	2.8
11	329	2039.5	0.050	19.8	2.3	39.4	12.1	160.2	14.4	9.2
12	274	1228.2	0.041	8.7	2.4	15.4	11.7	83.7	10.2	7.9
13	433	931.5	0.045	8.9	11.4	30.5	3.2	97.5	12.8	4.0
14	388	621.4	0.051	12.1	2.7	33.3	13.3	71.5	6.7	7.1
15	347	901.1	0.051	10.3	10.8	31.3	3.5	64.4	13.5	2.5
16	179	622.6	0.051	10.4	21.1	47.1	9.2	72.9	9.5	8.1
17	329	592.0	0.044	7.1	4.2	39.7	9.7	69.8	10.7	6.2
18	354	528.0	0.045	10.4	2.8	26.8	9.7	34.9	3.6	7.1
19	333	520.8	0.043	10.1	7.4	34.3	1.0	47.4	7.3	0.9
20	199	641.1	0.048	9.9	2.5	31.4	10.8	50.8	10.4	7.0
21	239	610.4	0.055	9.2	4.2	17.6	11.3	62.8	2.1	8.3
22	166	615.3	0.057	10.4	24.4	28.7	2.7	44.5	9.5	3.9
23	226	722.2	0.055	10.0	32.4	30.1	11.4	46.1	10.3	7.0
24	238	724.7	0.055	14.5	3.5	36.0	16.2	57.0	13.3	8.3
25	.	725.5	0.055	10.6	3.7	23.3	16.0	51.3	6.0	9.0
26	186	752.5	0.063	25.1	51.2	49.3	8.5	116.3	14.6	7.8
27	207	548.7	0.040	5.7	2.5	4.8	11.7	65.8	2.0	7.6
28	207	586.0	0.028	3.4	2.7	10.2	4.4	36.7	6.9	0.0
29	203	618.9	0.048	9.9	35.9	77.5	14.6	33.5	8.7	8.0
30	197	596.9	0.047	6.1	3.3	10.9	13.7	52.3	8.5	4.8
31	180	532.8	0.027	2.6	15.2	45.9	10.1	54.1	0.3	3.7
32	179	634.9	0.048	6.8	13.6	45.1	9.0	40.3	10.7	2.5
33	259	572.6	0.048	6.5	2.7	17.6	12.7	19.4	10.8	5.0
34	214	582.3	0.034	4.0	7.8	160.6	9.2	61.5	1.7	2.7
35	164	486.4	0.026	2.6	9.2	43.4	0.0	71.8	4.6	0.0
36	195	712.1	0.083	0.0	0.0	0.0	0.0	149.4	12.1	11.9
37	197	596.9	0.032	3.7	13.8	36.1	5.2	65.5	5.3	2.6
38	184	536.4	0.031	3.9	8.9	16.8	6.5	138.7	2.9	4.7
39	131	1050.9	0.027	2.9	2.3	74.8	0.7	23.8	8.7	0.9
40	144	501.8	0.022	2.5	19.8	38.9	5.7	88.5	0.0	2.0
41	175	556.9	0.033	3.9	4.0	22.3	0.0	97.1	6.7	1.8
42	108	522.0	0.028	3.1	2.9	29.4	5.4	98.8	6.0	1.9
43	156	604.2	0.043	8.7	2.7	10.1	12.5	80.6	6.9	6.7
44	109	550.8	0.046	6.3	5.3	68.7	12.4	12.1	3.9	9.1
45	130	540.0	0.027	2.8	2.5	12.2	0.8	52.5	8.6	1.7
46	164	559.3	0.037	5.3	5.1	35.5	7.2	17.2	6.2	3.4
47	176	600.6	0.027	4.1	6.0	28.3	10.2	195.0	0.0	6.6
48	.	1211.3	0.223	363.2	1039.1	123.2	34.5	60.1	32.1	26.9
49	.	625.1	0.050	14.6	59.3	10.6	13.6	19.0	10.3	9.0

Table 4 (cont.)

CHATTANOOGA SHALE OUTCROP DATA

	PB	RB	SR	TH	U	V	Y	ZN	ZR
1	73.4	36.1	41.4	.	.	127.3	34.5	334	59.4
2	20.8	164.5	111.7	.	.	127.6	31.2	54.6	191.7
3	28.5	173.3	115.1	13.1	12.3	142.9	27.4	64.0	160.6
4	21.7	160.7	139.5	11.2	28.8	141.3	27.8	67.4	156.3
5	20.5	205.4	130.3	11.2	10.2	134.2	33.8	54.5	142.6
6	26.8	157.9	160.1	8.0	35.7	146.7	25.3	30.6	159.0
7	18.8	173.7	109.8	9.5	18.7	107.8	21.9	18.3	161.4
8	21.7	174.2	90.2	10.5	25.1	146.5	21.9	44.0	160.7
9	24.7	147.5	87.2	12.9	37.5	144.4	21.9	22.9	164.5
10	16.3	185.4	147.7	.	.	123.5	25.1	33.6	176.2
11	26.6	122.7	135.6	.	.	133.1	20.4	28.7	170.7
12	22.0	128.3	103.6	.	.	120.4	25.0	21.7	152.7
13	25.3	144.4	95.5	6.9	32.8	116.6	17.1	50.0	122.7
14	23.8	171.6	111.4	9.3	21.1	132.7	19.5	48.4	131.4
15	24.6	164.5	102.5	.	.	120.8	19.7	14.4	127.4
16	26.7	164.1	97.4	8.2	20.3	119.7	18.5	13.3	136.4
17	30.1	168.9	109.5	8.8	29.7	118.8	23.5	10.4	155.6
18	16.2	151.2	90.3	8.3	9.7	106.6	27.7	63.3	127.7
19	18.3	146.6	82.7	.	.	105.0	22.4	182	124.8
20	20.0	172.1	103.3	.	.	116.1	23.0	39.6	123.8
21	18.5	160.9	114.2	.	.	116.7	23.0	66.0	123.1
22	19.5	165.8	130.2	9.5	12.9	111.8	22.5	53.0	112.3
23	19.7	189.4	114.1	10.6	10.9	124.7	24.2	34.4	122.5
24	20.0	182.5	92.7	11.7	15.2	132.1	37.0	57.6	149.5
25	19.0	199.6	103.6	10.2	12.5	144.7	26.7	32.3	142.8
26	26.7	130.8	90.3	.	.	151.0	26.6	155	143.8
27	24.5	163.3	111.7	9.3	32.0	126.5	25.3	18.0	149.8
28	20.5	177.8	103.5	8.3	13.6	114.1	19.1	12.0	126.4
29	33.2	163.3	77.0	11.7	22.1	399.9	25.7	327	118.8
30	30.6	223.5	97.5	9.2	14.5	156.0	25.6	28.1	147.1
31	14.1	192.6	95.8	11.2	15.7	265.4	29.0	24.0	156.1
32	20.4	196.9	87.7	11.8	15.3	189.2	26.6	436	142.9
33	13.4	224.7	80.5	12.6	6.5	136.6	25.9	53.2	141.3
34	14.8	196.0	88.4	12.2	19.5	276.2	61.0	106	173.6
35	12.7	167.0	78.1	0.0	0.0	250.7	21.0	25.2	146.5
36	46.0	206.7	92.2	11.0	3.3	948.9	51.8	547	146.3
37	16.6	202.8	143.6	15.6	24.3	292.9	27.9	46.6	150.4
38	16.7	163.6	70.6	8.5	18.4	205.5	27.7	25.0	150.7
39	15.3	182.2	132.9	16.9	12.2	253.8	57.6	45.4	161.0
40	16.1	161.6	69.2	13.9	27.6	187.6	27.4	25.7	166.5
41	20.4	162.3	70.9	10.4	30.2	252.5	27.9	33.0	146.2
42	15.7	186.2	74.0	.	.	412.6	27.6	65.5	125.0
43	19.6	151.5	105.0	.	.	173.1	29.2	202	148.1
44	15.8	181.1	67.7	.	.	121.2	22.9	40.7	108.2
45	13.9	182.2	78.8	16.5	14.6	243.0	30.1	8.8	139.5
46	13.1	212.0	126.7	13.4	3.7	184.4	44.9	84.8	158.7
47	17.1	155.9	94.2	10.0	57.7	224.3	25.2	41.7	96.8
48	127.6	99.4	247.5	.	.	156.1	131	780	106.6
49	25.6	196.2	145.9	.	.	135.3	31.7	193	162.0

Table 4 (cont.)

CHATTANOOGA SHALE OUTCROP DATA

	B	BA	CO	CO	CR	CU	GA	MO	NB	NI
50	.	778.0	0.100	36.1	68.6	26.6	19.0	23.1	11.5	12.9
51	97	607.9	0.064	32.7	15.5	49.7	15.1	63.9	4.1	10.3
52	.	575.0	0.026	2.9	4.2	12.3	0.7	83.9	6.0	0.0
53	.	571.4	0.051	8.1	4.2	13.6	14.3	76.9	3.7	7.6
54	149	891.9	0.129	127.9	345.6	68.3	21.6	152.2	31.1	15.6
55	109	575.0	0.043	6.3	11.3	17.8	13.2	104.5	11.3	6.0
56	108	610.4	0.046	9.5	4.0	39.3	14.2	75.4	7.9	4.8
57	61	626.3	0.063	18.0	7.2	38.8	17.5	67.1	7.4	10.8
58	.	480.4	0.034	6.9	3.7	31.8	1.8	36.3	7.5	0.9
59	180	627.5	0.053	15.5	4.2	46.3	18.0	68.9	9.0	6.8
60	158	552.0	0.039	5.1	5.0	11.3	14.5	71.5	3.7	6.0
61	115	582.3	0.048	8.7	8.8	24.8	7.4	72.7	13.8	2.1
62	100	532.0	0.041	6.9	12.5	34.6	14.1	82.4	11.1	5.1
63	.	669.6	0.059	21.7	5.5	55.4	14.4	101.2	9.7	9.3
64	62	1026.5	0.178	124.2	482.3	77.9	44.7	147.0	20.7	30.5
65	.	564.1	0.035	4.3	2.7	31.5	5.8	25.0	8.6	0.0
66	148	514.9	0.034	5.4	9.2	26.6	10.1	60.6	1.1	3.9
67	110	531.6	0.033	3.5	2.5	13.0	2.5	55.5	4.2	0.0
68	570	273.1	0.128	7.6	10.4	22.9	9.7	19.5	4.4	4.9
69	570	171.6	0.099	4.0	13.0	40.0	4.8	20.8	1.5	0.5
70	116	274.2	0.087	14.1	7.7	318.4	11.3	20.9	2.3	9.2
71	102	202.9	0.067	4.2	6.8	248.3	2.2	27.2	4.9	1.0
72	126	260.9	0.068	9.1	10.0	333.1	11.4	42.5	1.8	7.1
73	310	529.2	0.037	6.8	3.7	23.8	10.4	85.2	1.5	4.1
74	125	743.6	0.066	33.6	62.9	105.5	9.4	61.0	9.9	6.3
75	134	631.2	0.060	32.1	43.3	105.8	20.9	116.8	8.9	11.1
76	143	418.4	0.019	2.5	38.5	0.0	1.3	69.2	1.7	0.0
77	144	480.4	0.028	3.3	14.8	4.0	7.6	140.7	1.0	1.7
78	135	534.0	0.051	7.6	9.5	23.3	1.6	81.4	7.5	3.1
79	203	2695.3	0.067	21.4	10.5	52.3	14.8	84.1	9.1	11.5
80	210	423.0	0.021	2.3	19.2	2.5	0.0	34.4	3.9	0.0
81	219	421.9	0.017	2.4	14.7	2.1	2.4	43.7	1.0	0.0
82	140	547.2	0.036	5.7	10.3	14.6	7.4	89.5	6.2	3.0
83	170	499.4	0.034	6.3	10.1	21.6	8.7	82.7	1.6	4.7
84	130	484.0	0.027	4.0	6.1	11.5	0.0	69.8	3.2	0.0
85	137	532.8	0.034	4.5	13.1	11.5	8.5	60.2	5.1	3.2
86	126	414.0	0.024	3.4	50.4	0.0	0.9	56.4	0.0	0.0
87	480	741.1	0.151	17.2	77.5	56.8	14.6	47.9	21.3	11.3
88	121	584.7	0.043	6.5	8.9	21.0	10.5	71.2	8.6	5.1
89	830	599.4	0.041	5.5	4.5	19.3	9.4	70.1	5.7	5.3
90	210	561.7	0.039	4.4	4.6	13.1	8.3	91.7	0.3	5.2
91	180	91.1	0.034	3.6	2.8	14.9	0.5	18.1	1.8	0.0
92	100	510.1	0.041	4.1	7.2	5.0	13.1	27.2	0.0	6.3
93	103	494.7	0.036	3.3	3.5	21.9	4.7	18.2	5.2	0.0
94	200	584.7	0.044	8.4	7.1	46.1	11.4	128.8	7.8	6.3
95	169	519.7	0.034	4.2	6.3	31.6	10.2	79.6	6.1	4.3
96	153	459.2	0.033	3.8	18.8	10.8	7.9	109.5	0.7	4.4
97	380	446.4	0.026	2.8	7.7	40.0	0.0	30.5	3.5	0.0
98	143	419.5	0.023	2.6	27.6	8.1	1.5	26.6	1.3	0.0

Table 4 (cont.)

CHATTANOOGA SHALE OUTCROP DATA

	PB	RB	SR	TH	U	V	Y	ZN	ZR
50	16.2	195.6	136.0	.	.	187.3	30.5	64.4	152.5
51	27.3	142.0	88.6	9.4	12.4	140.7	29.8	92.1	187.7
52	13.0	161.3	210.0	.	.	120.9	24.2	14.7	159.5
53	26.1	179.2	97.0	.	.	149.6	25.3	25.3	142.1
54	59.5	130.4	92.4	10.1	47.3	180.1	31.3	85.4	153.5
55	24.8	186.6	111.0	10.5	41.7	150.7	27.6	35.9	153.0
56	27.0	170.2	129.8	8.7	20.7	136.7	26.6	27.5	170.7
57	25.3	191.9	100.5	10.7	12.9	141.5	28.9	85.0	138.3
58	17.9	121.3	106.6	.	.	103.1	32.6	42.0	122.7
59	22.2	195.1	92.6	12.0	21.4	162.0	26.3	85.7	135.2
60	22.0	172.1	94.3	10.6	27.0	131.8	22.6	33.8	129.8
61	23.4	164.6	98.0	12.4	25.6	133.0	24.0	33.6	126.8
62	20.0	199.8	28.7	8.6	29.8	151.8	31.3	126	152.0
63	25.1	170.4	82.7	.	.	147.5	26.9	87.8	136.1
64	65.8	150.6	84.9	8.7	21.0	394.2	38.3	161	127.6
65	18.2	189.3	93.5	.	.	144.3	27.0	23.3	146.5
66	21.4	167.1	85.0	10.8	23.2	166.2	24.4	103	133.6
67	19.0	198.5	99.4	10.4	15.3	131.4	25.1	32.8	143.7
68	15.2	76.6	106.8	.	.	86.4	33.2	92.1	125.7
69	13.3	91.4	91.8	.	.	69.2	22.4	46.3	123.5
70	13.7	94.8	89.1	.	.	101.9	41.1	222	95.5
71	11.5	97.0	77.6	.	.	121.4	34.5	239	123.6
72	13.9	92.8	73.7	.	.	236.1	56.4	613	87.9
73	19.4	152.3	94.1	.	.	132.1	26.0	41.2	155.5
74	26.6	138.3	80.8	.	.	161.4	26.8	55.5	146.2
75	31.0	138.0	94.9	.	.	166.1	30.3	167	200.4
76	20.3	127.4	95.4	11.6	56.3	117.6	19.7	6.5	171.4
77	18.4	125.8	86.0	9.7	60.4	135.7	22.9	13.2	168.8
78	20.3	146.4	110.4	4.6	46.2	139.8	22.2	26.8	157.7
79	26.6	157.7	98.3	11.3	36.2	151.6	31.7	103	148.0
80	14.0	149.6	81.7	8.8	15.9	98.0	19.3	7.7	132.0
81	13.4	156.2	90.7	.	.	97.3	16.7	9.7	123.3
82	20.1	154.9	85.1	10.7	33.4	119.3	23.5	26.5	143.4
83	18.8	144.6	72.1	8.5	8.0	137.5	25.3	40.5	141.6
84	15.2	135.2	62.1	8.7	21.6	137.2	20.5	33.2	115.9
85	20.2	166.1	80.7	10.1	25.3	135.9	25.6	29.1	132.2
86	16.4	140.0	68.1	.	.	122.2	15.2	23.0	107.0
87	22.6	137.5	231.7	9.9	19.2	126.0	79.6	124	108.6
88	20.2	176.9	83.6	11.7	25.2	149.1	28.9	51.3	135.9
89	20.1	176.4	89.1	12.1	25.9	161.6	26.3	39.9	81.1
90	19.2	190.1	84.4	9.5	32.5	254.0	27.9	70.5	143.4
91	17.1	212.7	81.7	12.4	11.0	145.6	28.4	70.4	132.5
92	17.3	225.1	76.9	11.7	17.1	132.6	27.9	68.6	121.3
93	17.4	220.9	82.2	12.4	13.6	131.4	27.9	26.7	135.5
94	20.0	179.3	83.3	12.0	29.6	192.9	27.8	113	148.5
95	19.0	163.9	95.0	14.4	29.8	232.1	0.0	66.6	142.5
96	18.3	159.0	85.5	10.6	32.5	245.2	0.0	46.7	129.3
97	13.4	131.3	61.4	7.1	12.6	279.5	27.0	86.8	114.9
98	16.3	132.2	72.5	9.9	29.1	177.5	16.2	28.5	115.7

Table 4 (cont.)

CHATTANOOGA SHALE OUTCROP DATA

	B	BA	CD	CG	CR	CU	GA	MD	NB	NI
99	148	524.4	0.028	3.2	3.5	21.5	7.9	41.6	1.2	6.7
100	153	572.6	0.041	5.0	11.6	36.3	0.0	47.3	10.3	2.6
101	157	623.9	0.047	9.7	30.8	127.0	12.7	298.0	10.1	7.9
102	930	322.3	0.108	10.3	4.7	37.7	15.8	13.2	8.9	7.6
103	220	0.0	0.231	3.2	4.5	13.1	14.5	18.6	4.6	12.8
104	.	171.6	0.111	4.3	5.1	176.4	2.1	16.2	8.2	4.8
105	139	260.9	0.061	4.2	4.3	375.0	14.9	21.0	5.8	14.4
106	290	132.2	0.148	4.4	8.3	83.8	3.9	18.2	8.1	4.1
107	213	305.4	0.063	5.7	20.2	273.3	8.7	28.2	9.4	8.6
108	108	311.1	0.054	5.6	5.3	93.8	11.3	16.8	6.1	5.5
109	500	168.4	0.111	4.8	3.5	37.0	11.7	18.2	4.0	10.9
110	295	390.6	0.035	6.7	7.2	260.4	2.4	22.3	7.2	2.6
111	202	577.4	0.041	8.9	2.2	17.0	7.9	127.4	6.8	6.2
112	166	644.8	0.039	4.9	2.3	7.2	10.7	78.3	5.5	6.8
113	167	697.0	0.061	23.6	43.7	52.5	7.0	89.4	17.2	5.1
114	134	288.7	0.072	9.3	47.5	253.9	10.3	71.2	10.1	10.2
115	890	334.7	0.044	6.4	2.2	164.2	7.7	29.1	6.2	5.5
116	168	363.2	0.039	5.6	2.9	15.7	9.5	85.4	7.0	4.8
117	135	486.4	0.029	3.8	2.4	50.7	0.0	64.5	10.9	0.0
118	216	531.6	0.053	12.5	3.3	44.5	14.5	90.3	7.4	8.6
119	238	440.5	0.043	4.6	5.0	19.5	0.1	23.9	13.6	0.6
120	130	548.4	0.049	8.1	18.0	51.2	10.8	90.8	10.1	7.8
121	156	461.6	0.049	5.8	4.3	20.1	11.2	29.2	14.4	6.0
122	134	543.6	0.047	7.0	3.6	48.9	12.9	140.1	4.9	9.0
123	193	552.0	0.042	5.2	11.3	38.5	0.0	118.0	13.1	1.0
124	168	499.4	0.048	6.2	2.6	18.7	7.1	21.2	11.4	5.2
125	197	542.4	0.044	5.5	5.0	8.4	9.6	100.7	6.5	6.6
126	219	531.6	0.037	5.3	3.4	44.7	0.0	87.1	12.0	0.0
127	216	547.2	0.049	5.8	10.7	19.7	9.0	22.2	10.7	6.3
128	169	559.3	0.040	5.5	6.7	16.3	5.8	95.3	12.4	5.3
129	213	727.2	0.046	6.6	2.3	10.6	9.8	78.2	7.0	7.7
130	175	753.8	0.043	5.0	5.0	16.6	3.5	78.7	11.3	0.0
131	178	992.8	0.047	6.2	2.3	20.4	12.2	55.3	8.3	8.0
132	170	626.3	0.040	4.8	8.6	35.9	2.5	150.0	13.2	2.1
133	210	511.3	0.040	5.0	16.2	37.7	8.6	185.7	10.2	5.9
134	216	569.0	0.042	5.5	4.6	70.2	9.2	66.5	11.6	4.9
135	159	447.5	0.042	6.8	5.0	110.4	9.4	35.4	7.3	8.2
136	105	6321.2	0.131	5.5	2.6	30.3	0.4	24.6	13.5	1.0
137	156	550.8	0.039	5.7	10.5	72.8	0.1	153.3	6.3	0.0
138	367	411.4	0.037	6.6	19.4	17.3	0.0	79.9	0.0	0.0
139	304	481.6	0.052	9.0	2.4	16.2	0.0	151.4	10.2	0.0
140	238	564.1	0.034	6.1	4.1	37.8	0.0	77.3	1.8	0.0
141	247	1108.4	0.073	20.2	21.8	44.6	14.4	85.4	14.1	6.9
142	166	864.5	0.049	6.6	2.6	39.2	12.8	85.6	5.4	7.4
143	335	897.2	0.038	5.2	2.4	48.5	1.0	215.5	7.5	0.0
144	190	765.2	0.040	4.4	2.9	76.8	10.2	116.3	2.2	7.3
145	302	1029.2	0.046	7.1	40.0	75.2	8.0	180.3	9.8	4.7
146	361	668.3	0.039	4.1	17.8	78.7	6.9	41.0	6.4	4.9
147	296	821.6	0.051	9.5	4.6	88.3	3.4	41.2	5.1	4.2

Table 4 (cont.)

CHATTANOOGA SHALE OUTCROP DATA

	PB	RB	SR	TH	U	V	Y	ZN	ZR
99	15.2	149.9	75.7	10.2	26.7	507.4	24.3	71.0	117.6
100	17.4	164.7	70.3	.	.	239.4	27.2	49.1	140.0
101	24.2	169.8	74.3	.	.	696.1	25.7	642	122.6
102	110.4	137.2	114.5	9.7	4.9	107.2	44.8	50.3	151.3
103	23.6	13.6	110.2	.	.	16.8	8.7	202	38.1
104	9.1	82.1	96.8	.	.	60.8	30.1	266	95.8
105	12.3	78.9	99.7	5.7	6.5	93.7	31.9	405	79.6
106	12.2	55.4	120.5	3.5	2.6	43.8	29.2	66.7	74.1
107	11.1	114.4	82.4	8.6	9.4	175.3	40.5	97.1	142.6
108	12.7	155.1	85.4	10.9	5.5	105.9	27.6	105	147.6
109	12.4	86.6	91.3	.	.	78.9	23.7	76.6	128.4
110	13.8	150.1	69.4	10.0	14.5	120.4	36.7	147	102.8
111	23.4	137.0	121.8	10.5	54.2	141.0	30.4	13.1	186.9
112	28.2	175.9	108.3	9.4	32.7	146.5	25.8	18.3	171.1
113	32.6	169.0	106.1	10.8	34.8	155.8	27.4	102	153.5
114	16.3	110.8	81.4	0.5	21.0	312.4	51.3	461	110.5
115	15.6	129.9	68.7	5.2	12.5	123.3	36.7	76.0	108.6
116	26.8	152.2	91.2	4.0	33.0	137.3	19.9	25.3	143.9
117	19.7	155.1	77.5	5.3	25.3	158.8	20.8	26.7	136.7
118	24.3	170.4	79.5	12.2	39.8	194.2	28.1	84.2	146.9
119	17.6	210.9	88.3	14.7	24.4	190.0	31.9	63.0	138.3
120	21.5	191.3	90.2	12.3	37.8	314.6	29.4	141	150.0
121	20.3	220.8	90.1	5.9	22.4	217.6	29.5	73.1	131.2
122	24.0	171.9	147.5	13.9	44.4	546.6	30.3	235	69.8
123	19.7	185.9	149.9	15.1	40.4	441.1	32.4	91.4	51.6
124	18.6	215.4	89.7	5.8	15.8	154.5	28.7	73.1	130.3
125	21.6	187.4	93.7	6.6	37.6	278.3	29.7	68.9	146.3
126	18.8	163.1	70.0	9.6	35.5	167.2	26.1	76.2	138.3
127	19.9	188.6	154.3	.	.	125.5	27.9	48.5	163.7
128	26.0	148.3	77.4	7.3	45.2	133.1	18.9	21.0	160.0
129	21.3	146.7	94.3	6.5	34.1	173.8	18.8	28.4	150.1
130	20.9	177.9	106.7	7.0	38.1	167.5	17.1	26.5	137.2
131	17.4	170.1	180.4	8.7	39.2	168.2	24.8	42.6	159.8
132	20.7	163.3	134.1	9.4	58.3	499.0	28.4	68.8	146.7
133	24.3	149.3	91.1	10.6	63.4	820.0	31.2	69.7	148.1
134	25.2	153.9	76.0	9.2	25.4	435.0	31.3	229	150.3
135	26.7	171.0	80.9	9.5	31.9	552.5	42.3	478	150.9
136	12.8	26.0	303.0	6.2	5.2	36.7	63.6	78.6	136.8
137	17.4	143.0	80.8	18.6	53.6	484.3	34.8	333	140.9
138	16.9	104.2	72.1	14.4	44.0	139.2	15.8	35.5	132.1
139	24.5	111.4	93.9	.	.	153.6	13.0	15.5	141.6
140	23.8	115.4	71.1	.	.	171.3	16.5	159	139.4
141	30.3	161.5	101.3	18.7	35.8	201.3	25.3	91.4	143.4
142	25.1	187.2	106.8	.	.	191.1	26.1	57.7	158.5
143	19.4	149.7	81.0	19.8	66.3	347.7	28.6	136	136.2
144	20.7	161.8	79.9	.	.	658.3	33.2	274	153.9
145	22.4	154.4	108.0	14.6	57.2	868.9	39.4	325	148.4
146	18.2	156.4	92.4	15.1	33.1	347.1	53.0	121	149.0
147	30.8	118.5	83.1	13.1	46.2	345.6	59.7	590	105.3

Table 4 (cont.)

CHATTANOOGA SHALE OUTCROP DATA

	B	BA	CD	CO	CR	CU	GA	MO	NB	NI
148	150	895.5	0.048	8.9	3.8	138.2	13.3	41.7	10.0	10.7
149	179	781.8	0.096	39.5	146.1	92.3	12.8	87.4	21.2	10.0
150	150	646.0	0.067	22.4	10.5	43.5	12.1	173.2	10.6	11.4
151	148	762.7	0.059	15.9	2.1	22.3	5.5	132.3	3.9	64.1
152	130	4578.3	0.078	55.7	117.1	103.3	12.5	136.4	19.5	11.3
153	.	817.8	0.108	37.0	234.9	53.7	28.4	45.2	16.7	14.3
154	109	1144.3	0.063	19.6	14.2	53.7	18.6	129.6	14.0	10.8
155	116	868.4	0.066	28.0	28.2	65.8	19.6	169.9	9.7	12.7
156	209	760.1	0.034	4.6	6.8	84.0	5.6	118.5	8.9	2.3
157	117	693.3	0.063	12.4	4.4	36.7	18.1	21.4	7.4	10.0
158	219	1102.9	0.095	69.1	164.9	78.0	14.2	128.8	17.7	11.1
159	195	3058.0	0.045	12.7	18.4	74.9	10.0	151.7	9.4	7.0
160	157	2716.6	0.048	7.1	2.4	69.4	13.0	139.3	9.5	7.5
161	187	5781.2	0.047	5.2	2.8	98.6	15.2	105.3	8.2	10.0
162	252	771.6	0.041	5.7	19.3	124.0	2.9	68.3	10.8	4.2
163	224	370.0	0.022	4.6	19.0	10.9	7.9	15.2	5.4	2.3
164		274.1	0.061	4.1	2.9	51.5	8.1	18.6	2.2	6.4
165		261.0	0.091	5.5	23.0	223.7	7.5	33.7	6.2	5.8
166		305.3	0.036	10.7	9.9	119.0	7.8	20.7	4.6	5.2
167		397.0	0.032	10.3	15.6	65.7	7.1	21.0	5.5	2.2
168		284.9	0.041	4.6	8.9	91.2	9.1	19.8	0.5	4.8
169		325.0	0.053	12.9	13.1	130.0	5.4	31.7	8.3	4.1
170		259.9	0.059	5.8	3.2	120.0	8.7	29.7	0.1	6.1
171		569.1	0.069	11.3	39.0	76.0	6.7	68.2	13.4	5.5
172		414.1	0.046	8.7	12.1	95.6	15.0	74.8	7.5	6.6
173		380.7	0.035	4.9	5.6	66.5	9.0	59.3	6.9	3.3
174		394.4	0.038	4.7	8.3	38.2	10.0	66.0	0.3	5.0
175		346.3	0.027	3.9	3.6	89.5	1.7	57.6	4.8	1.0
176		368.9	0.030	3.3	18.2	57.3	8.5	50.7	1.1	2.2
177		389.7	0.033	3.2	17.7	29.0	10.9	20.7	0.0	4.0
178		468.5	0.050	6.2	13.5	31.6	3.8	23.0	7.9	2.1
179		386.0	0.037	4.7	6.2	69.3	11.7	62.4	4.4	5.3
180		539.3	0.092	31.2	57.3	67.0	20.1	78.8	14.6	9.4
181		357.8	0.021	2.4	19.7	68.1	7.0	32.2	0.3	1.1
182		441.5	0.033	3.6	2.8	47.8	0.0	47.8	9.9	0.0
183		411.8	0.025	2.8	33.2	25.5	3.8	31.3	0.2	2.9
184		323.4	0.019	2.3	7.9	62.9	0.0	46.2	5.7	0.0
185		568.3	0.111	55.1	312.7	35.7	30.3	77.3	16.4	15.1
186		378.1	0.024	2.9	30.3	89.1	5.2	64.4	5.9	1.3
187		493.3	0.057	9.4	2.8	53.5	14.7	121.6	9.0	9.0
188		292.7	0.061	6.7	2.3	35.6	2.7	119.7	8.2	0.9
189		352.8	0.058	20.5	11.2	60.5	12.1	139.4	7.6	9.0
190		343.8	0.043	5.0	2.5	129.0	9.8	68.2	3.8	6.1
191		398.2	0.048	6.6	31.8	129.0	4.7	43.2	11.2	2.8

Table 4 (cont.)

CHATTANOOGA SHALE OUTCROP DATA

	PB	RB	SR	TH	U	V	Y	ZN	ZR
148	20.0	163.1	112.4	.	.	169.8	45.5	143	186.8
149	44.1	147.2	111.4	8.0	14.9	211.3	24.4	72.7	183.8
150	32.7	136.0	246.3	5.1	58.9	166.2	22.8	37.7	168.9
151	25.0	117.0	122.7	.	.	144.3	21.2	50.5	123.0
152	45.6	125.9	134.2	.	.	230.7	30.0	82.7	180.9
153	28.8	208.4	135.3	.	.	235.1	26.4	59.1	79.7
154	36.5	173.1	117.1	8.8	44.4	251.5	28.3	101	171.7
155	35.6	172.9	94.2	.	.	276.0	36.6	113	153.8
156	22.4	161.9	82.1	7.9	40.1	463.0	34.5	231	158.2
157	28.1	216.6	147.7	10.4	11.3	161.2	26.6	80.5	162.9
158	36.2	140.1	119.2	8.7	60.6	131.6	39.0	61.6	145.6
159	39.2	136.4	148.7	.	.	188.9	29.0	44.3	182.0
160	30.6	160.6	116.2	13.5	116.1	249.7	30.6	42.5	180.1
161	30.4	158.1	261.1	11.4	104.4	429.1	37.2	87.8	183.6
162	20.9	153.5	81.4	7.4	28.2	491.2	32.2	224	146.3
163	11.0	150.6	80.2	.	.	99.5	17.5	54.6	134.5
164	10.2	119.8	210.9	5.0	6.1	86.8	23.2	72.1	113.3
165	14.7	105.1	835.2	6.0	3.6	114.7	26.9	56.5	156.9
166	11.6	147.7	159.4	11.8	5.1	94.7	43.5	136	128.5
167	11.7	154.5	161.2	11.6	6.5	93.3	25.4	84.0	142.3
168	11.1	154.5	19.3	9.5	6.0	90.7	49.3	100	142.1
169	14.3	148.8	280.9	7.8	10.5	112.8	35.0	96.8	141.6
170	13.8	125.9	250.2	8.0	12.3	112.7	27.0	64.1	120.6
171	22.9	172.2	322.5	10.5	30.7	155.3	25.6	24.2	176.8
172	21.7	168.0	249.8	8.5	15.3	128.0	28.4	26.3	160.5
173	20.7	152.3	194.0	8.7	19.7	112.6	27.6	16.9	168.7
174	18.1	152.6	213.2	7.1	21.9	124.8	23.2	23.8	157.3
175	16.1	144.7	195.4	8.3	17.5	110.0	25.7	11.2	159.8
176	18.1	147.1	192.5	9.1	19.3	112.2	23.8	19.6	164.6
177	16.6	168.9	171.6	9.2	10.4	117.2	27.4	23.4	166.7
178	20.9	171.4	187.3	10.4	10.3	124.6	27.4	31.1	159.0
179	17.7	117.8	158.0	12.1	20.8	119.0	32.0	32.3	81.3
180	26.6	141.2	175.4	9.0	26.4	166.1	24.3	100	148.8
181	10.0	163.1	188.8	9.2	29.4	113.2	26.5	23.7	179.9
182	13.6	161.0	104.1	8.4	30.8	130.1	25.6	24.1	181.3
183	11.7	163.3	197.5	9.2	31.5	124.6	28.4	8.7	227.8
184	8.8	145.0	153.5	11.4	31.8	113.3	27.2	9.1	186.5
185	37.8	131.2	112.7	10.5	33.4	183.1	22.8	51.2	145.5
186	13.9	143.5	154.9	12.7	48.5	126.1	25.8	11.3	85.2
187	21.9	149.7	149.0	14.3	62.9	152.8	26.6	14.0	193.3
188	26.0	104.3	86.7	9.5	47.4	111.7	18.5	6.5	119.1
189	34.5	110.5	102.9	13.2	73.0	126.9	26.2	47.8	124.3
190	33.9	146.6	67.9	12.9	31.5	537.8	26.2	17.4	137.7
191	51.2	159.3	80.4	12.8	25.9	395.0	12.0	184	137.8

Table 5

CHATTANOOGA SHALE OUTCROP DATA
NORMATIVE MINERALOGY

NO.	QTZ	ILL	KALL	CHLOR	PYP	CARB	FELD	ACES	S+	R
1	.	.	.	.	.	.	.	.	.	.
2	.	.	.	.	.	.	.	.	.	.
3	24.51	39.02	12.69	0.00	5.74	0.04	6.58	0.89	5.19	5.34
4	23.60	37.74	8.03	0.00	4.11	0.02	6.36	0.91	5.29	13.93
5	25.50	47.81	10.53	0.00	3.87	0.42	8.06	0.87	3.39	-0.45
6	31.83	40.70	4.39	0.00	2.79	0.03	6.86	0.87	3.09	9.45
7	29.13	41.29	7.86	0.00	3.42	0.14	6.96	0.94	0.00	10.26
8	28.24	42.28	8.23	0.00	1.62	0.15	7.13	0.93	0.22	11.21
9	28.25	38.23	4.86	0.00	3.88	0.03	6.44	0.88	0.09	17.33
10	.	.	.	.	.	.	.	.	.	.
11	38.01	30.43	0.98	13.73	1.59	0.01	5.13	0.99	0.00	9.12
12	39.84	31.02	6.65	0.00	3.65	0.53	5.23	0.95	0.00	12.13
13	37.03	32.90	1.39	13.00	0.97	0.06	5.55	0.75	0.00	8.36
14	30.88	39.61	6.35	0.00	4.24	0.15	6.68	0.85	0.15	11.09
15	29.58	38.92	5.84	0.00	4.30	0.03	6.56	0.80	0.00	13.97
16	33.34	36.65	6.47	0.00	4.55	0.03	6.18	0.89	0.43	11.45
17	31.23	39.42	5.51	0.00	3.85	0.00	6.64	0.90	3.22	9.23
18	40.11	32.90	9.47	0.00	4.15	1.32	5.55	0.95	2.35	3.20
19	40.19	32.01	8.59	0.00	4.10	0.93	5.40	0.89	3.04	4.87
20	34.45	37.24	8.33	0.00	4.54	0.78	6.28	0.92	3.78	3.68
21	32.27	34.28	6.99	0.00	4.78	1.98	5.78	0.90	5.76	7.26
22	33.51	36.16	6.07	0.00	4.85	1.27	6.09	0.88	6.10	5.07
23	31.29	40.60	6.98	0.00	5.15	0.45	6.84	0.87	1.69	6.12
24	27.77	40.11	6.96	7.80	2.00	0.36	6.76	0.96	0.00	7.29
25	30.63	38.92	9.30	0.00	3.61	1.09	6.56	1.03	0.00	8.85
26	31.20	29.54	4.08	8.88	3.62	0.01	4.98	0.97	0.00	16.70
27	31.36	37.14	7.61	0.00	2.51	0.48	6.26	0.99	0.00	13.65
28	36.10	37.74	9.46	0.74	1.07	0.39	6.36	0.85	0.00	7.29
29	30.86	34.08	7.76	0.00	4.47	1.10	5.74	0.86	0.65	14.48
30	23.40	43.57	11.31	0.00	4.08	0.41	7.34	1.02	1.17	7.71
31	26.07	41.69	12.51	0.00	0.82	0.74	7.03	1.15	0.00	10.00
32	24.52	39.61	12.21	0.00	3.42	0.69	6.68	1.05	0.00	11.81
33	24.07	48.31	6.92	7.49	1.37	0.00	8.14	1.76	0.00	1.95
34	21.83	40.21	15.32	0.00	1.09	0.77	6.78	1.00	0.00	13.01
35	28.38	41.10	9.85	0.00	1.91	0.03	6.93	1.16	0.00	10.65
36	25.36	42.87	9.36	0.00	4.68	1.75	7.23	0.88	0.00	7.86
37	26.22	43.47	9.23	6.99	0.02	0.06	7.33	0.93	0.00	5.76
38	27.88	37.34	8.25	0.00	1.87	0.80	6.29	0.97	0.00	16.49
39	22.19	36.65	18.25	5.03	0.06	0.00	6.18	1.20	0.00	10.44
40	33.92	35.96	10.43	0.00	1.12	0.86	6.06	1.06	0.00	10.59
41	32.85	35.37	7.75	2.97	1.16	0.06	5.96	0.92	0.00	12.96
42	28.93	38.43	8.50	0.00	1.95	0.93	6.48	0.90	0.00	13.88
43	31.00	33.79	9.28	0.00	2.69	1.11	5.69	1.00	0.00	15.43
44	19.52	38.43	4.36	6.95	1.22	0.01	6.48	0.74	0.00	22.29
45	21.70	38.23	10.47	2.31	0.26	0.03	6.44	0.91	0.00	19.66
46	21.44	42.87	14.88	9.32	0.32	0.06	7.23	1.03	0.00	2.86
47	38.61	29.83	9.02	0.00	2.89	0.38	5.03	0.67	0.28	13.28

Table 5 (cont.)

CHATTANOOGA SHALE OUTCROP DATA
NORMATIVE MINERALOGY

NO.	QTZ	ILL	KAOL	CHLOR	PYP	CARB	FELD	ACES	S+	R
48	.	.	.	.	.	.	.	.	.	.
49	.	.	.	.	.	.	.	.	.	.
50	.	.	.	.	.	.	.	.	.	.
51	29.82	33.59	4.53	11.07	2.83	0.00	5.66	1.02	0.00	11.48
52	.	.	.	.	.	.	.	.	.	.
53	24.19	40.11	6.55	0.00	4.21	0.46	6.76	0.90	0.17	16.62
54	24.11	30.03	4.69	0.00	10.27	0.06	5.06	1.01	0.00	24.76
55	22.94	41.79	7.05	0.00	3.51	0.63	7.04	0.90	0.74	15.39
56	25.61	40.50	7.64	0.00	3.76	0.30	6.83	1.05	0.00	14.30
57	23.88	42.08	7.24	0.00	5.20	0.54	7.09	0.96	0.00	13.00
58	.	.	.	.	.	.	.	.	.	.
59	24.34	40.60	6.35	3.40	2.68	0.01	6.84	0.97	0.00	14.30
60	31.99	38.53	6.38	0.00	3.56	0.63	6.49	0.87	0.23	11.31
61	30.27	38.43	5.08	0.00	4.33	0.70	6.48	0.84	0.34	13.52
62	23.32	40.90	11.44	0.00	2.30	0.74	6.89	1.02	0.00	13.39
63	.	.	.	.	.	.	.	.	.	.
64	22.80	32.90	7.86	0.00	11.63	4.51	5.55	0.90	0.86	12.99
65	.	.	.	.	.	.	.	.	.	.
66	36.40	36.16	7.85	0.00	2.53	0.53	6.09	0.93	0.00	9.53
67	24.98	43.66	9.35	0.00	2.36	0.57	7.36	1.00	0.00	10.71
68	23.38	27.46	3.10	0.00	2.15	51.59	4.63	1.51	1.26	-15.1
69	24.31	31.61	2.12	0.00	1.98	44.16	5.33	0.76	3.39	-13.7
70	20.24	30.43	2.51	0.00	2.88	24.61	5.13	1.24	6.66	6.31
71	23.76	33.29	1.36	0.00	2.29	22.69	5.61	1.10	4.72	5.17
72	18.94	29.74	1.08	0.00	3.11	14.94	5.01	1.17	6.46	19.54
73	23.04	36.16	8.56	0.00	3.33	0.35	6.09	1.08	0.25	21.03
74	20.36	31.81	8.22	0.00	4.58	0.00	5.36	1.02	0.00	28.64
75	27.18	33.88	8.92	0.00	3.99	0.03	5.71	1.05	0.00	19.25
76	29.47	34.87	8.82	0.00	1.23	0.01	5.88	1.18	0.00	18.53
77	27.73	33.19	7.02	0.00	2.34	0.03	5.60	1.09	0.80	22.20
78	25.77	38.73	5.32	0.00	4.28	0.80	6.53	1.03	1.70	15.84
79	24.76	37.64	6.40	0.00	4.34	0.25	6.34	0.92	0.00	19.34
80	35.60	37.64	7.00	0.00	1.50	0.53	6.34	0.92	0.00	10.47
81	36.23	37.64	7.05	0.00	0.45	0.57	6.34	0.80	0.00	10.91
82	29.71	38.13	5.80	0.00	2.83	0.51	6.43	0.91	0.00	15.69
83	35.79	33.59	6.93	0.00	1.89	0.52	5.66	0.91	0.00	14.71
84	34.26	34.38	6.71	0.00	2.13	0.72	5.79	0.88	0.00	15.12
85	29.67	38.82	6.57	0.00	1.98	0.68	6.54	0.93	0.00	14.79
86	26.92	41.99	5.56	0.00	2.97	0.64	7.08	0.95	0.00	13.89
87	14.35	34.08	5.02	0.00	3.99	23.19	5.74	0.64	18.95	-0.11
88	23.30	41.99	5.71	0.00	3.70	1.03	7.08	0.89	0.94	15.36
89	24.03	41.29	6.22	0.00	3.11	0.65	6.96	0.93	0.00	16.81
90	22.94	42.97	6.92	0.00	2.08	0.71	7.24	0.95	0.00	16.18
91	25.36	49.89	9.04	0.00	2.79	0.96	8.41	0.89	0.49	2.16
92	23.15	49.20	8.88	0.00	3.07	0.95	8.29	0.87	0.45	5.25
93	26.94	51.17	7.22	0.00	0.95	0.96	8.63	0.91	0.00	3.21
94	27.14	39.71	6.03	2.23	1.68	0.12	6.69	0.99	0.00	15.40

Table 5 (cont.)

CHATTANOOGA SHALE OUTCROP DATA
NORMATIVE MINERALOGY

NO.	QTZ	ILL	KAGL	CHLOR	PYR	CARB	FELD	ACES	S+	R
95	30.30	38.33	5.41	0.00	2.88	0.69	6.46	1.04	0.00	14.89
96	31.35	36.75	6.34	0.00	2.73	0.62	6.19	1.02	0.09	14.91
97	31.10	33.79	6.82	0.00	1.68	0.83	5.69	1.70	0.00	18.39
98	31.16	33.69	4.81	0.00	2.13	0.87	5.68	0.88	0.77	20.00
99	30.02	32.60	5.39	0.00	1.35	0.81	5.50	0.80	0.00	23.54
100	22.55	37.54	5.28	0.00	2.34	0.83	6.33	1.04	0.00	24.09
101	25.77	34.18	6.97	0.00	2.54	0.39	5.76	0.71	0.00	23.68
102	14.49	44.55	3.02	0.00	3.73	29.27	7.51	1.49	4.55	-8.63
103	23.95	0.00	5.50	0.00	1.49	60.14	0.00	.	0.36	.
104	.	.	.	.	.	.	.	.	.	.
105	24.10	0.00	22.61	0.00	1.66	42.77	0.00	1.28	8.65	-1.07
106	22.27	21.04	3.39	0.00	1.78	63.80	3.55	0.47	6.32	-22.6
107	22.20	34.97	1.53	0.00	2.40	18.57	5.89	0.98	3.53	9.92
108	25.54	45.25	1.93	0.00	2.75	14.47	7.63	0.76	3.38	-1.70
109	27.52	30.82	2.14	0.00	2.46	42.56	5.20	0.69	2.19	-13.6
110	25.93	41.29	4.14	0.00	2.67	3.62	6.96	0.96	2.50	11.93
111	24.82	34.87	8.40	0.00	3.41	0.00	5.88	1.00	0.00	21.63
112	26.21	42.48	7.70	0.00	2.51	0.73	7.16	0.97	0.00	12.25
113	24.88	40.70	6.90	0.00	5.45	0.43	6.86	0.91	1.08	12.78
114	20.29	36.16	0.00	0.00	3.11	15.37	0.00	1.08	3.85	20.15
115	22.53	39.52	0.61	0.00	2.70	7.24	6.66	1.02	1.95	17.79
116	32.66	36.92	3.35	0.00	3.31	0.70	6.56	0.94	0.67	12.89
117	36.19	37.64	7.05	0.00	2.43	0.81	6.34	0.85	1.06	7.62
118	23.83	42.87	4.66	0.00	4.31	0.91	7.23	0.93	4.56	10.69
119	24.69	51.67	5.36	0.00	3.13	2.03	8.71	0.91	0.50	3.01
120	23.14	45.54	4.16	0.00	3.72	1.03	7.68	0.95	2.57	11.20
121	23.46	52.26	4.15	0.00	3.64	1.64	8.81	0.86	0.40	4.77
122	23.20	40.70	5.05	0.00	2.39	0.93	6.86	0.97	0.00	19.90
123	23.71	43.17	5.03	0.00	2.43	1.07	7.28	0.97	0.00	16.36
124	23.79	51.86	3.50	0.00	3.90	1.81	8.74	0.86	0.12	5.43
125	25.13	43.57	5.06	0.00	3.36	0.88	7.34	0.96	2.01	11.70
126	28.51	40.60	5.75	0.00	3.10	0.86	6.84	0.94	1.96	11.45
127	27.08	51.07	3.18	0.00	3.64	1.41	8.61	1.03	0.08	3.89
128	27.66	41.59	1.57	0.00	2.83	0.62	7.06	0.85	0.00	17.53
129	31.00	39.91	2.32	0.00	3.61	0.81	6.73	0.83	1.44	13.35
130	23.68	45.25	1.08	0.00	3.13	0.85	7.63	0.81	3.14	14.44
131	24.70	41.99	1.24	0.00	3.13	1.44	7.08	0.86	1.17	18.39
132	23.04	42.38	1.40	0.00	2.56	1.24	7.14	0.91	0.00	21.33
133	25.75	37.14	1.03	0.00	3.07	1.04	6.26	1.00	2.75	21.37
134	21.35	39.52	1.26	0.00	2.10	1.20	6.66	1.15	0.00	26.77
135	21.92	41.39	2.96	0.00	1.40	1.03	6.98	1.54	0.00	22.76
136	37.68	8.59	4.70	0.00	1.68	58.33	1.45	3.72	4.08	-20.2
137	23.77	39.52	4.83	0.00	3.04	3.02	6.66	1.26	0.35	17.55
138	24.72	35.66	3.31	0.00	4.24	0.01	6.01	0.92	0.21	24.91
139	25.65	39.61	0.75	0.00	5.90	0.04	6.68	1.06	1.50	18.80
140	26.90	39.91	3.17	0.00	3.70	0.01	6.73	0.94	0.00	18.62
141	23.35	43.07	3.50	0.00	5.89	0.79	7.26	0.99	0.00	15.15

Table 5 (cont.)

CHATTANOOGA SHALE OUTCROP DATA
NORMATIVE MINERALOGY

NO.	QTZ	ILL	KAGL	CHLOR	PYR	CARE	FELD	ACES	S+	R
142	23.04	45.25	5.15	0.00	3.47	0.60	7.63	0.98	0.33	13.55
143	23.32	39.12	4.52	0.00	2.51	1.01	6.59	1.07	0.00	21.87
144	24.74	37.74	4.51	0.00	2.36	1.17	6.36	1.12	0.00	22.00
145	25.97	36.26	3.76	0.00	3.33	1.20	6.11	1.50	0.00	21.88
146	25.46	37.34	4.13	0.00	2.72	1.15	6.29	1.94	0.49	20.47
147	21.90	33.00	2.61	0.00	4.79	0.51	5.56	2.54	0.33	28.77
148	20.91	43.07	4.24	4.78	0.58	0.00	7.26	1.61	0.00	17.55
149	25.51	42.28	3.44	0.00	7.50	0.00	7.13	1.08	1.08	11.98
150	23.65	41.10	0.23	0.00	5.36	0.00	6.93	1.11	3.48	18.15
151	19.94	40.60	0.58	0.00	5.84	0.54	6.84	0.94	2.34	22.38
152	27.47	35.47	2.51	0.00	6.36	0.06	5.98	0.97	0.87	20.32
153	.	.	.	.	.	.	.	.	.	.
154	18.95	43.66	0.00	17.19	0.62	0.00	7.36	1.15	0.00	11.03
155	19.33	42.87	0.00	16.87	0.79	0.01	7.23	1.05	0.00	11.86
156	26.43	40.90	3.50	0.00	2.19	0.78	6.89	1.22	0.00	13.09
157	16.93	54.04	4.82	0.01	2.34	1.59	9.11	1.03	0.00	10.13
158	21.70	39.61	1.98	0.00	7.92	1.05	6.68	0.65	4.72	15.69
159	36.22	34.08	3.91	0.00	4.22	0.00	5.74	1.11	4.13	10.58
160	25.36	44.16	2.14	0.13	1.87	0.34	7.44	0.98	0.00	17.58
161	27.71	40.31	2.70	0.00	2.00	0.76	6.79	1.08	0.00	18.64
162	27.43	38.73	2.96	0.00	2.32	1.83	6.53	1.29	0.68	17.74
163	49.64	31.32	7.33	3.15	1.05	1.46	5.28	0.94	0.00	-0.16

APPENDIX B

Geochemical and Normative Mineralogical logs for
the Eastern Kentucky Black-shale Outcrop Belt.

Figure 3. Regional and stratigraphic variation in the concentration of Silicon (in percent) in Lewis County-Cumberland County cross-section.

Figure 4. Regional and stratigraphic variation in the concentration of Titanium (in percent) in Lewis County-Cumberland County cross-section.

Figure 5. Regional and stratigraphic variation in the concentration of Aluminum (in percent) in Lewis County-Cumberland County cross-section.

Figure 6. Regional and stratigraphic variation in the concentration of Iron (in percent) in Lewis County-Cumberland County cross-section.

Figure 7. Regional and stratigraphic variation in the concentration of Magnesium (in percent) in Lewis County-Cumberland County cross-section.

Figure 8. Regional and stratigraphic variation in the concentration of Calcium (in percent) in Lewis County-Cumberland County cross-section.

Figure 9. Regional and stratigraphic variation in the concentration of Sodium (in percent) in Lewis County-Cumberland County cross-section.

Figure 10. Regional and stratigraphic variation in the concentration of Phosphorus (in percent) in Lewis County-Cumberland County cross-section.

Figure 11. Regional and stratigraphic variation in the concentration of Sulfur (in percent) in Lewis County-Cumberland County cross-section.

Figure 12. Regional and stratigraphic variation in the concentration of Boron (in ppm) in Lewis County-Cumberland County cross-section.

Figure 13. Regional and stratigraphic variation in the concentration of Barium (in ppm) in Lewis County-Cumberland County cross-section.

Figure 14. Regional and stratigraphic variation in the concentration of Cadmium (in ppb) in Lewis County-Cumberland County cross-section.

Figure 15. Regional and stratigraphic variation in the concentration of Cobalt (in ppm) in Lewis County-Cumberland County cross-section.

Figure 16. Regional and stratigraphic variation in the concentration of Chromium (in ppm) in Lewis County-Cumberland County cross-section.

Figure 17. Regional and stratigraphic variation in the concentration of Copper (in ppm) in Lewis County-Cumberland County cross-section.

Figure 18. Regional and stratigraphic variation in the concentration of Gallium (in ppm) in Lewis County-Cumberland County cross-section.

Figure 19. Regional and stratigraphic variation in the concentration of Molybdenum (in ppm) in Lewis County-Cumberland County cross-section.

Figure 20. Regional and stratigraphic variation in the concentration of Niobium (in ppm) in Lewis County-Cumberland County cross-section.

Figure 21. Regional and stratigraphic variation in the concentration of Nickel (in ppm) in Lewis County-Cumberland County cross-section.

Figure 22. Regional and stratigraphic variation in the concentration of Lead (in ppm) in Lewis County-Cumberland County cross-section.

Figure 23. Regional and stratigraphic variation in the concentration of Rubidium (in ppm) in Lewis County-Cumberland County cross-section.

Figure 24. Regional and stratigraphic variation in the concentration of Strontium (in ppm) in Lewis County-Cumberland County cross-section.

Figure 25. Regional and stratigraphic variation in the concentration of Thorium (in ppm) in Lewis County-Cumberland County cross-section.

Figure 26. Regional and stratigraphic variation in the concentration of Uranium (in ppm) in Lewis County-Cumberland County cross-section.

Figure 27. Regional and stratigraphic variation in the concentration of Vanadium (in ppm) in Lewis County-Cumberland County cross-section.

Figure 28. Regional and stratigraphic variation in the concentration of Yttrium (in ppm) in Lewis County-Cumberland County cross-section.

Figure 29. Regional and stratigraphic variation in the concentration of Zinc (in ppm) in Lewis County-Cumberland County cross-section.

Figure 30. Regional and stratigraphic variation in the concentration of Zirconium (in ppm) in Lewis County-Cumberland County cross-section.

Figure 31. Regional and stratigraphic variation in the concentration of normative Illite (in weight percent) in Lewis County-Cumberland County cross-section.

Figure 32. Regional and stratigraphic variation in the concentration of Normative Quartz (in weight percent) in Lewis County-Cumberland County cross-section.

Figure 33. Regional and stratigraphic variation in the concentration of normative Pyrite (in Weight percent) in Lewis County-Cumberland County cross-section.

Figure 34. Regional and stratigraphic variation in the concentration of Organic Carbon ('R', in weight percent) in Lewis County-Cumberland County cross-section.

Figure 35. Regional and stratigraphic variation in the concentration of excess Sulfur (in weight percent) in Lewis County-Cumberland County cross-section.

Figure 36. Regional and stratigraphic variation in the concentration of normative Carbonate (in weight percent) in Lewis County-Cumberland County cross-section.

Figure 37. Regional and stratigraphic variation in the concentration of normative Kaolinite (in weight percent) in Lewis County-Cumberland County cross-section.

Figure 38. Regional and stratigraphic variation in the concentration of normative Feldspar (in weight percent) in Lewis County-Cumberland County cross-section.

BLACK-SHALE STRATIGRAPHY GROUP

1.0 Executive Summary

This quarter has largely been devoted to completing radioactive isopach maps for the black-shale sequence in eastern Kentucky. Six work maps were completed by the end of January and sent to John Roen, U.S.G.S. However, because of confusion and misunderstandings regarding instructions for preparation of the maps, parts of these maps will have to be redone. Remaining parts of the quarter were spent in consultation with John Roen and workers in other states, regarding the correct way to develop the radioactive isopach maps. These problems will be discussed in a following section.

2.0 Contract Objectives

1. Interpretation of stratigraphic data from outcrops.
2. Interpretation of petrographic data from sampled cores.
3. Formulation of depositional model.
4. Progress on paleontological and paleoecological study.
5. Progress on isopach, structural contour, and lithofacies maps.

3.0 Technical Progress

3.1 Stratigraphic Interpretation

- 3.1.1 All work finished with completion of Dennis Swager's thesis. The thesis was sent to M.E.T.C. for review and potential publication. As yet, we have heard nothing about the review.

3.2 Petrographic Interpretation

- 3.2.1 All work finished with completion of Mike Miller's thesis. The thesis was sent to M.E.T.C. for review and potential publication. At present, we have heard nothing about the review.

3.3 Depositional Model

A preliminary working model similar to that of Heckel (1977) based on the quasi-estuarine circulation concept has been postulated, but much more corroborative data is needed. Much of this data is now being developed by fellow workers, and is presently unavailable. We estimate that much of this data will be available late in this year at which time we will proceed fully to develop our interpretations. Currently, library research is continuing as is interpretation of available data.

3.4 Paleontological and Paleoecological Study

3.4.1 During this quarter, we collected more samples (microfossils) in field and visited the University of Cincinnati Geology Museum from which we borrowed a number of black-shale specimens for study. These specimens are currently being studied and photographed. An extensive paleontological bibliography is continuing to be compiled.

3.4.2 More collecting in the field, museum visitations, and literature research are needed.

3.5 Isopach, Structural Contour and Lithofacies Maps

3.5.1 During January, 5 radioactive isopachs for the following units were prepared: Cleveland Sh. Mbr., Huron Sh. Mbr., Olentangy Sh. Mbr., Rheinstreet Sh. Mbr., and the Chattanooga Shale. The completed work maps were then sent to John Roen, U.S.G.S. We were subsequently informed that there were great discrepancies between the Kentucky and West Virginia maps. After consultation with workers from adjacent states and reexamination of our own material, it was found that the workers in Kentucky and West Virginia had used different shale-base lines. This apparently resulted from misunderstandings and incomplete specifications at our group meetings. We left the meetings thinking that we were to use an average shale-line from outside the black-shale sequence, whereas many others thought they were to use a gray shale from within the black-shale sequence. We used a shale base line based on the Borden shale, which overlies the black-shale sequences. Our reasons for this were:

1. The Borden shale is outside the black-shale sequence and would provide a radioactively unbiased average shale. Those gray shales

within the black-shale sequence contain black-shale interbeds and are decidedly more radioactive than what we thought an average gray shale should be.

2. The Borden is everywhere present. Most of the gray-green shale horizons pinch out westwardly in eastern Kentucky, and are not everywhere available for use in eastern Kentucky.

Others, however, used the Chagrin Shale equivalent within the black-shale sequence or multiple shale lines. Because we used the relatively nonradioactive Borden Shale as a base line, our maps exhibit much greater thicknesses of radioactive shale than those of adjacent states, where a more radioactive green shale was used.

As a consequence of this misunderstanding, it will take 3 to 4 additional months to regenerate these radioactive isopach maps.

Work has also progressed on the well-log inventory. The well-log inventory for Boyle, Clark, Garrard, Lincoln, and Lee counties has been completed this quarter. Only Breathitt, Estill and Floyd counties remain to be completed, and we believe that these will be finished in June. Once the inventory is completely finished, work can begin on isopach and structure contour maps.

STRATIGRAPHIC CHARACTERIZATION AND DATA HANDLING

1.0 EXECUTIVE SUMMARY

Regional cross-sections and conferences have facilitated Stratigraphic Characterization; and the Middlesboro Syncline study has clarified the structural milieu significantly.

Significant misunderstandings between PI-WHCS, EGSP Data Bank-USGS, and KRG are being cleared up and effective use of the data bank is more nearly in sight. In the meantime we are fulfilling the contract requirements according to the current directives.

2.0 CONTRACT OBJECTIVES

The Rome Trough section is nearly ready for delivery (it was due March 31). Data sets are delivered on schedule. The basic idea of cooperative work between PI and KRG (envisioned in the contract) seems on the verge of reality. It will make a better data bank.

3.0 TECHNICAL PROGRESS

3.1 Stratigraphic Characterization. Surface and subsurface cooperation is going smoothly.

3.1.1 Rome Trough Regional cross-section is assembled for submission as a deliverable except for a short neutral text being written to be entered on the format, which is otherwise fully drafted except as to legend.

3.1.2 Middlesboro Syncline Study with P. E. Potter (University of Cincinnati) covers about 9,000 square miles in 24 counties of Tennessee, Virginia and Kentucky, about 1/3 of it being north and west of the Pine Mountain Fault. The geologic base is in final form ready to receive datum points. The data are essentially complete and total 977 structure and isopach datum points, of which 196 (43 outcrops and 153 boreholes) are in and southwest of the Middlesboro Syncline. The Eastern Longitudinal and the Big Stone Gap Tie Sections, in their present states, are references to the stratigraphy and structure.

Data Handling

Transfer of data to the EGSP Data Bank in Denver has been (excluding outcrop data) entirely by correction and addition to wells already in the WHCS system on the PI comma-format. The comma-format is unfeasible for new wells; and our proposal to submit new wells directly to WHCS for their encoding is (according to latest report) nearly ready for implementation.

Between one-quarter and one-half of the submissions which were returned for additional work have been processed and sent back. A new operations change, which will reduce the correction load, and ease new submissions, awaits written confirmation for implementation. New data sets submitted in the quarter were 248, slightly above the contract rate.

Resource Evaluation. The basin-wide study of thickness of hyper-radioactive shale snagged on an inconsistency of definition between Kentucky and adjacent states.

Energy and Mission of EGSP. E.N. Wilson was invited to give a talk on oil, gas, and energy in Appalachia to an informal roundtable of the University of Kentucky Appalachian Studies Center. A modified text is attached.

OIL, GAS AND ENERGY IN APPALACHIAN KENTUCKY

(Annotated and slightly modified text of an informal talk by Edward N. Wilson, Kentucky Geological Survey, for the Appalachian Roundtable Lunch, March 14, 1979 in Room 365, Student Center, University of Kentucky.)

I. INTRODUCTION

I should like to begin with a story to illustrate the economic dimension of oil and gas production. Rotary drilling is a bit turning round-and-round against the rock, with a thin mud being circulated to cool the bit, plaster the sides of the hole, and bring up pieces of ground-up rock. By looking at the ground-up rock one can see oil and/or suspect gas in it; but the process of drilling prevents one having any idea how much. So naturally the industry has a tool to test for quantities when it becomes necessary. I shall not forget my first introduction to that tool.

When I left the University of Tennessee to become district geologist for a small oil and gas company in Evansville, Indiana, I was a real ignoramus regarding oil and gas technology; so George (E.V.) Kerr (a former contractor and driller in Texas, Mexico, and such romantic places and supervisor of the company's interest at the well) was an absolute goldmine of useful information for me. He was also a raconteur of no mean ability, and in-between-times at the drilling rig he regaled me with stories of wells he had known. It seemed his happiest moments were when "he called out the sandtester and got 900' of oil," or "he called out the sandtester and it flowed oil." In every way he made a real big thing out of the decision to call out this simple, necessary tool which he called the "sandtester." So I remember George bursting into the dog house in the middle of the night shouting "We gotta show, we gotta show, we gotta show!" So OK we gotta show. I slid down from the top bunk where I had been at horizontal parade rest, washed the sample and put it under the microscope while George bounced around me with "Shall I call out the sandtester, shall I call out the sandtester, shall I call out the sandtester?" Well, I could see oil in some unprepossessing rock, so with the aplomb allowed tyros making a decision nobody could fault I authorized George to "Call out the sandtester." That is when I discovered that the cost to rent the measly ol' sandtester for 8 to 12 hours was almost exactly my salary for the month! (That well was ultimately a dry hole, and cost approximately 4 years of my salary.)

II. SOME GENERAL REMARKS ABOUT ENERGY

Energy in some form enhances and ameliorates our lives,

whether it be the mule that relieves Loweezy Smith from the plow, or firewood that warms the cave, or such very specific things as electricity, which makes aluminum a useful metal instead of merely a precious one.

- A. Energy is a complicated continuum. It includes the separate sectors of production, processing, transportation, and utilization, each of which requires special technologies to develop. The production sector is the critical one now. It is not like the other sectors, and unfortunately the differences are little understood and less appreciated. Economics and planning in the other sectors presuppose a supply of the resource. Production is the much different matter of finding and exploiting the supply.
- B. Energy comes in different forms, from different resources, such as hydroelectric or nuclear electric power; heat from coal, oil and/or gas; etc. The resources are variously distributed. Some resources can be used directly, as one may burn coal in the fireplace; some must be processed, as now nuclear fuel must be turned into electricity; some can be processed to upgrade the quality or value of the material, such as stripping natural gas, refining oil to make multiple products, or washing coal to reduce its environmental impact.
- C. Energy may be produced, processed, and used in a very small way by a very small local unit, all in the same locality like a factory with its own gas well. More typically, however, energy delivery to the consumer is a huge interregional integrated complex, each region producing, processing, exporting, importing, and using those forms of energy as suits their resources, needs, and relative prices. Energy is a very substantial segment of the national and international economy, and involves the social and political fabric, it requires suitable government institutions and regulations. But just because they come from the government, regulations aren't necessarily suitable!
- D. There is a natural competition, based on price, between oil, gas, and coal. Thus one may understand that gas may be prized for its cleanliness and convenience, oil for its convenience in automotive transport, and coal for its ease of processing and transport and its low price. This is not to say that there are no variations in content of each which might affect particular uses or support special price levels, nor that in some cases certain constituents might preclude a particular fuel from a specific use—for example, sulfur and low fusibility prevents a coal from being sold for metallurgical coke—but in a significant sense Oil is Oil, Gas is Gas, and Coal is Coal.

- E. Energy sources may be valued or compared by their energy contents. If we measured energy contents in British Thermal Units (BTU), for ease of comparison we might say that gas has 1,000 BTU per standard cubic foot, oil has 6,000,000 BTU per barrel, and coal 12,000 BTU per pound. This isn't exactly right; but it makes for easy comparisons where gas is 1,000,000 BTU per MCF and coal 24,000,000 BTU per ton; so 24 MCF gas = 4 barrels oil = 1 ton coal. Or to compare prices, gas at \$3.00 per MCF is \$3.00 per million BTU, oil at \$15.00 per barrel is \$2.50 per BTU, and coal at \$24.00 per ton is \$1.00 per million BTU.
- F. Within the individual fossil fuels, coal, oil, and gas, there are quality variations which may give a worldwide market for one coal and a limited price potential for another; one oil may be a good resource for paraffin or for gasoline, another for road asphalt; or some gas might be pure methane as it comes from the ground and another might have water or sulfur (H_2S) or natural gas liquids which need to be removed before marketing. There is a natural free-market hierarchy of price levels depending on quality and energy contents of a given fuel. But there is no basis for a price differential so that "old oil" is worth less than \$6.00 per barrel, "new oil" about \$11.00 per barrel and oil that comes from our overseas friends is worth \$13.00 and up per barrel plus an inflationary balance of payments. In this sense, oil is oil and gas is gas. (Transport costs, and variations in coal rank affect the market for coal; and there is nearly a free market for it.)
- G. I would like to offer the following as summary conclusions or defensible propositions, which incidentally I am eager to defend given any appropriate forum.
1. Energy problems lie in the sector of production. National Energy Policy has been drawn from a prejudiced analysis of processing, transport, and marketing sectors of the energy industries, and punishments applied to the production sector.
 2. Given a reasonable economic climate with reasonable interfuel competition and free market pricing, the United States can be energy independent for the foreseeable future.

III. OIL AND GAS IN EASTERN KENTUCKY

In Kentucky, west and east, commercial coals occur only in Pennsylvanian rocks, whereas most oil and gas occurs in the Mississippian and deeper rocks. The geological map of the State (Figure 1) in showing the surface occurrence of Pennsylvanian rocks, shows where the coal basins are. In eastern Kentucky, oil and gas occur almost exclusively at depth under the coal. (You can see Mississippian rock

peeping out from under Pennsylvanian rock around both coal basins.) Similarly in western Kentucky, oil and gas occur principally below the Western Coal Basin.

A. Oil and gas typically occur together: exploration methods are therefore the same. But exploitation technologies are quite different. Although oil and gas occur together, they may occur in different proportions. Generally, gas increases relative to oil with increasing depth. There are regional variations, too. In western Kentucky in a typical pool, the amount of gas is too small to be saved economically, whereas in eastern Kentucky gas is more common than oil, and pools with essentially no oil are common. We are examining this anomaly and think we understand it.

B. The Oil and Gas Map of Kentucky (the two eastern sheets) show the distribution of known and developed oil and gas pools in Appalachian Kentucky (See Figure 2.).

1. Light green indicates abandoned oil pools and dark green producing oil pools. Bull Creek in Perry and Letcher Counties is an example of a field with oil below a gas column. Actually oil was discovered at Ulvah at the south end, gas at the north end near Cornettsville; and subsequent drilling connected the two. The greatest efficiency and yield is when oil and gas production rates are planned and executed together. However, the demand for gas from Bull Creek has been such that the operator, a gas utility, has had to exceed the maximum efficient rate (MER) on several occasions.
2. Blue signifies waterflooded or secondary production pools. Big Sinking in Lee and adjacent counties is the largest oil production unit in the state. It has yielded 100,000,000 plus barrels of oil since 1920 by primary production, vacuum, and gas injection, and finally by waterflood.

Primary production uses reservoir energy and obtains 5% to 20% of the oil-in-place. Secondary production, principally by waterflood, gets an additional 10% to 20% of oil-in-place by adding displacement energy and by doubling the costs. Tertiary production (miscible flood, etc.) introduces a chemical reaction and further displacement energy to produce nearly all of the oil in place at a further increase in costs. Miscible flood is now nearly commercial in the pilot stage.

Big Sinking has nearly played out by waterflooding. from the amount of production already from the pool, I estimate that there are still 150,000,000 barrels of oil in the ground there, most of which might be produced by tertiary flooding. However, "old oil"

pricing precludes miscible flooding; hence, this element of national policy prevents production of this oil which is already known in the ground. (Similarly, the 600,000,000 barrels accumulated Kentucky production indicate about a billion barrels of oil still in the ground in known pools.)

3. The pink and red patches are gas pools, and their predominance over green and blue illustrate the gas preference of eastern Kentucky mentioned earlier. Most of this gas is produced from sandstone and limestone, although the Ashland Pool in Boyd County also produces from the Devonian Shale.
4. The large purple area is the Big Sandy Pool in southeastern Kentucky. The purple signifies the area of Devonian Shale production.

Kentucky produces about 1/5 of the gas it uses. About 90% of its gas production is from eastern Kentucky, and 90% of that is from Big Sandy Field.

Shale is not usually a good reservoir rock, but this is a special case: the shales contain a great deal of organic matter and are very thick, so although they have very low permeability and interconnected porosity they still can yield enough gas to be worth saving.

Shale wells have a very low production rate, but long lives (30 to 50 years). Initial rates are seldom acceptable without stimulation. Formerly shooting (exploding black powder or dynamite in the hole) and now fracturing (creating or enlarging fractures in the rock by pumping fluids rapidly down the hole at high pressures) are the accepted stimulation methods; and the Eastern Gas Shales Project is seeking to find or develop a significantly more effective technology.

- C. Economics of Shale wells. Despite the importance of shale wells in eastern Kentucky production, they are not in an economic sense "commercial," that is, capable of yielding profit from the production. For example, in 1966 in Perry county (see Table 1) some dozen wells were completed as successful gas wells from the Shale. Their average depth was nearly 3,500 feet, their typical initial production was about 150,000 cubic feet of gas per day, and we might estimate that they cost \$25,000 each to drill and complete. The gross return from production (at that time about 10¢ per MCF) was \$15.00 per day, which same could be projected to nearly ten years (assuming a typical production history) simply to get the cost back without interest. You may ask me later why I think they "saved" the wells; but you see this is not economic in any fair market sense: the price of the product is out of line with the costs.

IV. WHERE DOES THE EASTERN GAS SHALES PROJECT COME IN?

- A. Despite uneconomic rates of production, over an extended period an awful lot of gas comes out of each well. We estimate that well over a trillion cubic feet has been produced from Kentucky alone, and the present producing area is obviously far from exhausted. In addition, for all that we presently know, large additional areas in Appalachia are prospective. These facts inspired DOE (then ERDA) to assemble the Eastern Gas Shales Project.
- B. We actually don't know the Petroleum Geology of the shale as we'd like: each one of us has his pet theories, each supported by some information. My guess is that different parts of the Basin will be found to be geologically different and will require different technological approaches to maximizing production rates and yields.

We are attacking stratigraphic characterization (the geologic description of the Shale) using surface and sub-surface geology, and geochemistry of the organic and mineral components. We are using data processing to record and manipulate research data and well histories. Concurrently we are trying to prove out ways of determining the gas-in-place content of the shale as a potential resource and trying to work out the production mechanisms to determine the recoverable gas. These two tasks are geological in nature.

- C. Given an understanding of the production mechanism, we can work on production technology, particularly in stimulating the rate of production. We presume that increasing the rate would make the individual well "commercial" and proportionately increase the total yield of the well.

I feel that stimulation technologies are on the edge of success in this regard.

V. SUMMARY

In my personal opinion based on my "expertise", I believe:

Oil and gas in Appalachia can make a larger and very significant contribution to the Appalachian energy budget and to the Kentucky and national energy resource base. (My silence about coal conceals a total and informed enthusiasm for it.)

National energy independence is wholly achievable; but unless there are significant changes, the present national energy policy will probably prevent it.

I think great things will come out of the Eastern Gas Shales Project and a lot of gas will come out of the eastern gas shales.

Table 1. COMPLETIONS IN PERRY COUNTY, KENTUCKY, 1966

Permit	Oper.-Well No.- Farm Name	Carter Coord.	Comp. Date	Total Depth	Result
14845	Ky W Va. Gas #1286 H M HALL	24-I-77	01/27/66	3438	Open Flow 73 MCFGPD/After Shot/Shale
14948	" " " " #1288 BRASHEAR, M	19-I-77	02/15/66	3110	OF 267 M/AS/Sh AS/After Shot
14984	" " " " #1289 BRASHEAR, F	19-I-77	12/28/65	1891	IP?B0/Maxon
15094	" " " " #1291 CORNETT, J D	5-H-77	01/13/66	3226	OF 24 M/Big Lm, 84M/AS/Sh
15117	" " " " #6913 COMBS & HALL	21-I-76	03/15/66	3557	OF 84 M/AS/Sh
15138	" " " " #6914 CORNETT, E	15-I-77	02/09/66	3498	OF 146M/AS/Sh
15216	" " " " #6915 SUMNER, E	4-H-78	03/12/66	2785	Junked hole; R/A sonde lost in it.
15410	" " " " #6918 WOODS, BEN J	2-H-76	03/08/66	3603	D&A after shot.
15633	" " " " #1294 BRASHEAR, M	19-I-77	04/08/66	3415	OF 94 M/AS/Sh
15769	" " " " #1296 BRASHEAR, W	19-I-77	04/04/66	3424	OF 440 M/Nat/Sh Nat = Natural
15799	" " " " #1297 MCINTYRE, J	1-H-77	08/31/66	3424	OF 119 M/Not Shot/Sh
15846	" " " " #1298 BRASHEAR, L	18-I-77	05/26/66	3661	OF 146 M/AS/Sh
15919	" " " " #6922 SUMNER, E	4-H-78	06/06/66	3145	OF 793 M/Big Lm
15936	" " " " #6925 CAUDILL, ROBT	11-H-76	06/09/66	3876	OF 146 M/AF?/Sh AF = After Frac
1597C	" " " " #6926 WOODS, T G	4-H-77	04/30/66	3227	OF 880 M/Nat/Sh
16012	" " " " #6928 CORNETT, J B	8-H-78	05/24/66	2702	OF 20B0/189M/Big Lm
16062	" " " " #1303 BRASHEAR, H	15-H-77	05/27/66	3545	OF 492M/Not Shot/Sh
16115	" " " " #6929 GAYHEART	5-J-77	05/18/66	3067	OF 169M/Nat/Sh
16142	" " " " #1305 BROWNING, WM	23-I-77	07/19/66	3807	OF 94M/AS/Sh
16241	" " " " #1306 BRASHEAR, G D	23-I-77	06/18/66	3223	OF 198M/AS/Sh
16363	" " " " #6931 HALL, JNO H	17-I-77	08/29/66	3226	OF 298M/AS/Sh
16462	" " " " #6933 BRASHEARS, J J	18-I-77	09/08/66	3550	OF 112M/AS/Sh
16641	" " " " #6935 DAVIS, R O	20-I-76	07/26/66	3820	OF 211M/Not Shot/Sh
16693	" " " " #1310 BRASHEAR, E C	14-H-77	09/14/66	3603	OF 60M/AF/Sh
16916	" " " " #1312 BRASHEAR, C	24-I-77	11/19/76	3341	OF 412M/AS/Big Lm & Sh
16971	" " " " #6936 PRATT, JAS D	21-I-76	08/26/66	3516	OF 84M/?/Sh
17158	" " " " #6937 CORNETT, WM	12-H-77	09/23/66	3438	OF 539M/Nat/Sh
17427	" " " " #1315 BRASHEAR, T	22-I-77	11/02/66	3321	OF 249M/AS/Sh
17450	" " " " #1316 BRASHEAR, G D	21-I-77	10/19/66	3600	OF 207M/AS/Sh

Figure 1 - Geological Map of Kentucky. Pennsylvanian rocks at surface P. Mississippian rocks at surface M. Mississippian rocks everywhere underlie Pennsylvanian rocks.